Impacts of improved sorghum varieties on farm families in Mali: A Multivalued Treatment Effects approach

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Abstract

Uptake of improved sorghum seed in Mali remains relatively limited, despite the economic importance of the crop. We first explore the adoption by Malian farm families of improved sorghum seed, differentiating between improved varieties and recently released sorghum hybrids, which are based largely on local Guinea materials developed through participatory, on-farm testing. We then examine impacts on farm families with a multivalued treatment effects model. Analysis is based on primary data collected from 628 farm families in the Sudanian Savanna. Reflecting the social organization of production in this region, we test the role of plot manager characteristics (including relationship to household head) as determinants of use. Given that farm family enterprises both consume and sell their sorghum harvests, we consider effects on consumption outcomes as well as yield. We find that plot manager characteristics, in addition to household wealth and labor supply, influence the use of improved varieties. The impact of hybrid use on yields is large and significant, positively affecting household dietary diversity and contributing to a greater share of the harvest sold. However, use of hybrids, as well as improved varieties, is associated with a shift toward

consumption of other cereals. Findings support on-farm experimental evidence concerning yield advantages, and suggest that encouraging the use of well-adapted sorghum hybrids may contribute to crop commercialization by smallholders.

I Introduction

Globally, combined with other farming practices, the diffusion of well-adapted, improved seed has enhanced the productivity of major food crops, including sorghum (Dalton and Zereyesus 2013; Evenson and Gollin, 2003). Since the devastating droughts in the West African Sahel during the 1970s-80s, national and international research institutes have invested to improve sorghum in this region (Matlon 1985, 1990). Yet, in Mali, use of improved sorghum seed remains relatively limited; estimated adoption rates as a share of crop's area vary between 13% and 30%, depending on the measurement approach, geographical coverage, and time period (Kelly et al., 2015). Numerous constraints, located at various nodes in the seed value chain, contribute to this situation (e.g., AGRA, 2010; Haggblade et al., 2015); these include a customary reverence for local seed and local varieties (Smale et al. 2010).

Not only is seed a key public good, but the fundamental role it plays in the well-being of smallholder farmers is also reflected in rural cultural norms, as has been documented for the drylands of Mali (e.g., Bazile 2006; Sperling et al. 2006). There, most smallholder farmers have few resources other than seed, their labor, and their family lands to produce what the cereal crops they need to survive. Moreover, sorghum is not a part of the vertically-integrated value chains that provides services for cash crops such as cotton via registered cooperatives.

Our objective in this paper is to examine the adoption and impacts on Malian farm families of improved sorghum varieties. We make several contributions to the literature on this topic. First, we include the first sorghum hybrids released in Mali, which are based largely on germplasm from the local Guinea landraces and were developed through participatory, on-farm testing. Earlier, quantitative adoption studies generated from farm data focused on exotic, improved varieties and "purified" landraces (e.g. Yapi et al. 2000) or on a single variety (Sanogo and Teme 1996); other recent studies relied on key informants (Ndjeunga et al. 2012). SDetailed case studies of adoption or seed use have also been conducted in particular villages or village clusters, such as the studies by Siart (2008) and Some (2011). We differentiate hybrids from other improved varieties, employing an ordered logit framework.

Second, we examine the impacts of each of these on the well-being of farm families. To do so, we employ a less frequently used approach: multivalued treatment effects (Cattaneo 2010). Many treatment applications with observational data in agricultural development pertain to binary assignment, which is addressed instead with propensity score matching. We test three models for robustness.

Finally, considering that Malian smallholders are farm families who both sell and consume their crop, our outcome indicators include plot yield, dietary diversity, and the share of sorghum in consumption and sales. Reflecting the social organization of production among sorghum growers, we include plot manager characteristics in addition to plot, household and market characteristics, among our control variables. So far, data from on-farm, participatory trials demonstrate strong yield advantages associated with Guinea-race, sorghum hybrids (Rattunde et al. 2013). Our study, a first glimpse of the impacts of these hybrids, draws on quantitative survey data collected from farm families.

Next, we present our methodology, including the data source, econometric strategy, and definitions of control and outcome variables. We then present results, include descriptive analyses, adoption regressions and treatment models. We draw conclusions and policy implications in the final sections.

II. Methods

A. Data source

The sample was drawn from a baseline census of all sorghum-growing households in 58 villages located in the Sudanian Savanna within the 800 mm isohyet. Villages surveyed included all those listed as sites where the national research program (Institut d'Economie Rurale-IER) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) have conducted testing activities via a network of farmer associations since 2009. Our findings are therefore representative of areas with at least some engagement by the national sorghum program, although adoption rates at the village level vary from 0% to 80%. Only villages with fewer than 1000 persons were included. The multi-visit survey was conducted in four rounds from August 2014 through June 2015, with a combination of paper questionnaires and computer-assisted personal interviews, by a team of experienced enumerators employed by IER.

The enumeration unit in the survey is the Entreprise Agricole Familiale (EAF, or family farm enterprise). According to the national agricultural policy act (Loi d'Orientation Agricole), the EAF is a production unit composed of several members who are related and who use production factors collectively to generate resources under the supervision of one the members designated as head of household. The head who can be a female or male member. The primary economic activity of the head is to ensure the optimal use of production factors. We would add that optimal use by these families considers the need to satisfy the consumption needs of the extended family. The head represents the EAF in all civil acts, including representation and participation in government programs. Alternatively, he or she may designate a team leader to supervise field work and manage the EAF on behalf of the head.

The family farm enterprise is a complex organization that consists of numerous plots on which multiple crops are grown. Plots are managed collectively and individually by various members of the family. Members generally include the head, his wives and children, married sons and their families, unmarried daughters and brothers of the head, and other relatives. Collective plots belonging to the whole EAF are managed by the household head or the team leader on behalf of the EAF. Individual plots belong to the EAF but are planted and managed by individual members, including both men and women. The production from these plots is not managed collectively. At each cropping season, the head distributes individual plots based on the needs of the family.

The sample of EAFs was drawn with simple random sampling from a census of all sorghum-growing households in the 58 villages. The sample was augmented by five percent to account for possible non-responses, leading to a total of 623 EAFs. The overall sampling fraction was 25%. Enumerators inventoried plots operated by each sampled EAF, grouping them by crop and plot management type. One plot was randomly sampled per group per EAF. The total sample of sorghum plots, including collectively and individually-managed fields, is 734.

All variety names reported by farmers and improvement status of varieties (local, improved, hybrid) were identified with the assistance of field technicians and also verified by sorghum breeders working with the national program at the International Crops Research Institute of the Semi-Arid Tropics.

B. Econometric strategy

Our analysis has two components. First, we explore the determinants of adoption with an ordered logit model, which enables us to differentiate between three ordered types of sorghum varieties: local (0), improved (1), and hybrid (2). The order, which is sometimes referred to as "improvement status," recognizes several potentially important differences between categories 1 and 2. Many improved varieties grown by farmers in this region are popular older releases, for which the seed may have been reused and shared among farmers. The hybrids have all been released since 2010 and introduced on a small-scale, pilot basis for testing by farmers. Moreover, although on-farm trial evidence demonstrates that these perform well with and without fertilizer, farmers and extension agents often portray that hybrids "require" fertilizer. In addition, it is recommended that farmers replace hybrid seed each year, although annual replacement is considered to be less important for improved sorghum varieties as long as good seed storage practices are followed.

In the second component of our analysis, we estimate an impact model. The Randomized Controlled Trial (RCT) is recognized as the "gold standard" of evaluation approaches because it eliminates selection bias (Imbens and Wooldridge 2009). In our context, adoption processes have occurred naturally, with occasional programmatic interventions, over a period of years; treatment assignment is nonrandom. We expect that adopters and non-adopters may be systematically different (Amare et al., 2012). Different methods have been used to address the question of establishing a counterfactual with non-experimental observations, including the class of treatment effect models, which we employ here. These make treatment and outcome independent by conditioning on covariates or controls.

Let y_{1i} denote the potential outcome of individual i if he/she adopts an improved variety of sorghum and let y_{0i} if not. Denote adoption status by a dummy variable, d_i. For each individual, we observe $y_i = d_i y_{1i} + (1- d_i) y_{0i}$; that is, we observe y_{1i} for adopters and y_{0i} for non-adopters. The average treatment effect (ATE) and the average treatment effect on the treated (ATET) are given by: ATE=$E[y_{1i} - y_{0i}]$; ATET= $E[y_{1i} - y_{0i} \mid d_i =1]$. With observational data, we really observe only the outcome under one of the possible states. The outcome in all other cases is, in fact, potential (Rubin, 1974).

In the case of binary treatment, matching has become a popular approach (Imbens and Wooldridge, 2009), especially given the challenges of identifying appropriate instruments for two-stage least squares analysis. However, matching is based on Conditional Independence Assumption, which stipulates that the covariate vector is expected to contain all the pre-treatment variables that affect the treatment assignment. A major issue with matching methods consists in the possible presence of hidden biases caused by unobservable covariates, which is not testable.

Cattaneo (2010) proposes an alternative approach that can be used with multivalued treatment and differs in the way that treatment enters the analysis and how the ATE is estimated. This approach is of particular interest because it addresses the potential existence of selection bias and results are robust. Following this approach, we model the potential-outcome as

$$y_i = \sum_{t=0}^{2} d_i(t) y_i\,(t)) \qquad (1)$$

where i is an index for observations (i=1, 2, …, N); y_i is the observed outcome of interest; $d_i(t)$ is an indicator that equals 1 if treatment type is t and 0 otherwise; and $y_i(t)$ is the outcome when treatment type is t; t is an index for treatment type (t = 0 if treatment type is control, 1 if improved variety, and 2 if hybrid variety).

We estimate three multivalued treatment models to estimate the ATE and ATE as a percent. The base model is the regression adjustment (RA) model. As a robustness check, we also present average treatment effects using augmented, inverse-probability weighted (AIPW) and inverse-probability weighted, regression adjusted (IPWRA), or "doubly robust" models. Augmented, inverse-probability weighted (AIPW) and inverse-probability weighted, regression adjustment (IPWRA) estimators model both the outcome and the treatment probability. These enable consistent estimation of treatment parameters when at least one of the outcome model or treatment model is correctly specified. For this reason, these models are known as having the "doubly robust property." Unlike AIPW and IPWRA approaches, RA estimators model the outcome without any assumptions about the treatment model. Therefore, AIPW and IPWRA estimators can be more efficient than RA (Cattaneo 2010).

C. Variables

The conceptual basis of our variety choice model is the non-separable model of the agricultural household (Singh, Squire and Strauss 1986), reflecting production by a farm family enterprise (EAF) that primarily deploys its own labor supply and land to address staple food requirements. In our survey data, we find virtually no evidence of land or labor markets; farm families consume, sell, and give their harvests to others.

According to this conceptual basis, we expect household capital endowments (wealth, education, labor supply) and proximity to market infrastructure to affect transactions costs and thus the likelihood of acquiring inputs in sorghum production. Although we would argue that typically, sorghum seed is not viewed as a purchased input in the same way as fertilizer or herbicides, endowments also affect access to information and knowledge about new seed types. The market network extends to weekly fairs conducted in villages. We include a dummy variable for the presence of a weekly fair in the village of the EAF.

In Mali, access to formalized extension structures ("encadrement") substitutes to some extent for commercial markets, influencing farmer access to inputs and services of various kinds, including subsidized fertilizer. To express "encadrement," we include a variable measuring the share of all plot managers in the village who are members of a registered cooperative.

Finally, as described above, we recognize the social organization of production in this region of Mali, and add the characteristics of the plot manager (education of the manager, whether the plot is managed by an individual other than the head; whether the manager is the wife or son of the head) among our explanatory variables. Table 1 shows the definitions and means of our independent variables in the ordered logit model, grouped in terms of plot manager, plot, household and market factors (Table 1).

Regarding the impact models, we are interested in potential outcomes that express impacts both on the supply of sorghum to the EAF and the EAF's consumption patterns. For yield, we specify the following fixed effects model:

$$yield=\alpha+\beta t'outcomecovar+ \Theta t'treatmentcovar +\mu,$$

where yield is sorghum yield in kg/ha, and *outcomecovar* is a vector of agricultural inputs applied on sorghum plots. Corresponding to a notional yield response function, we include input quantities per ha (seed, adult male labor, adult female labor, children's labor, fertilizers), as well as plot characteristics (time in minutes to travel from home to the plot; whether any form of structure has been built on the plot to offset soil and water erosion). *Treatmentcovar* is a vector of the same plot manager covariates that are included in the adoption analysis (with the exception of individual management; regressions did not converge with this covariate). Impact model control variables are shown in Table 2.

For consumption outcomes, following the conceptual basis of the agricultural household, we consider that relevant factors include both the supply side and those that enter via an expenditures constraint. We specify a fixed effects model that includes the production function aspects of the yield model (the supply outcome), and also the covariates that are likely to condition consumption, given the amount produced. These include household size, transfer receipts from absent household members (exogenous income), as well as household wealth in assets and the presence of a weekly market fair in the village, which affect transactions costs. Outcomes are defined as dietary diversity, the share of sorghum in household cereal consumption, and the share of harvested sorghum sold.

Outcome variable definitions are shown in Table 3. Of particular interest is the calculation of the Household Dietary Diversity Score, which represents a count of the different food groups consumed during the 7 days preceding the survey (Swindale and Bilinsky 2005). The EAF receives a score of 1 for each food group consumed at least once, 0 otherwise. The HDDS is the sum across scores. With ten groups, the hypothetical range of this indicator is 1-10. The HDDS including frequency of consumption augments the score to better capture the number of times a food group is consumed (Arimond and Ruel 2002a,b). For each food group, the EAF receives a score of 0 for frequencies fewer than four times per week, a score of unity for frequencies from 4 to 6 (inclusive) times per week, and a score of 2 for frequencies of seven or more. With ten groups, the hypothetical range of the sum is 1-20.

Table 3 also shows the differences in the means of each outcome variable by treatment. Without controlling for other factors, yields and dietary diversity appear to increase with improvement status. Given the same caveats, the share of sorghum in cereal consumption appears to decline with adoption of improved varieties and hybrids, while the share sold increases. These are the hypotheses we carry to the estimation.

In the next section, we begin with some descriptive statistics on our covariates, followed by the presentation and interpretation of regression results.

III. Findings

A. Descriptive statistics

Comparisons of adoption percentages for improved and hybrid seed by type of plot management characteristics are shown in Tables 4 and 5. Based only on bivariate statistics, adoption rates differ weakly (at about 10%) by gender of plot manager, with slightly higher rates visible among women (45% v. 39%). The same pattern is reproduced when comparing all collectively-managed to all individually-managed sorghum plots, since most collective sorghum plots are managed by heads or designates (of which there are only two women), and most individual plots are managed by women. Not shown here, but visible in the underlying data, patterns of use are nearly identical between the plots managed collectively by the head or designate, with slightly under 40% of these plots planted to an improved variety or sorghum hybrid in the 2014 main growing season.

Several considerations may explain these somewhat surprising findings. In our sampling strategy, we selected households that had adopted hybrids in 2013 in order to re-interview them in 2014 because they were "rare" during this pilot phase of hybrid seed development and dissemination. We purposively selected sorghum plots managed by women, although seed choice was not a sampling criterion at the plot level and thus does not explain the result. As part of the outreach strategy of the national sorghum improvement program, women farmers, in addition to men in the household, had been targeted. Still, the result that use of improved seed is at least as high (if not slightly higher) on individual fields, and particularly those managed by women, suggest that improved seed is clearly distributed among plot managers in a fairly equitable way. Relatively speaking, seed is a highly divisible input with relatively low cost and easy to transport, unlike fertilizer. Culturally, the right to seed is still an important social norm. In addition, sorghum is a food staple and qualitative work in this region by Siart (2008) and others has underscored the fact that women are increasingly planting sorghum on their individual fields, as compared to other crops they grew previously (such as legumes), in order to complement the family food supply.

Similarly, the data in Table 5 do indicate that the wife of the head is slightly more likely to grow improved materials than other family members who manage sorghum plots (p-value 7%; the son of the head is no different in this respect). Thus, we use "wife" and "son" of the household head as determinants of adoption and impact, rather than gender of the plot manager.

As expected, education of the plot manager plays a strong role in hybrid seed adoption, as shown in Table 6. The improvement status of the sorghum variety grown on the plot increases with the likelihood that the plot manager attained a primary school education. We expect the ability to read and write strongly affects receptiveness and access to new information, techniques, or technologies. Plot managers reported that on average, they had grown the local varieties planted in their plot for 11 years, as compared to 9 years for improved varieties and 3 for hybrids.

Virtually all sorghum plots were cultivated in the previous season (overall, 97%), and this did not vary by variety grown, which highlights the overall scarcity of land in this part of Mali and the fact that cereals, and especially sorghum, have been continuously cropped. All sorghum plots were rainfed. Because of the universality of these results, we do not report them in a table. Nor do mean distances to the plot from the household appear to differ significantly by sorghum variety type. Although soil types reported by farms did not appear to differ by variety type, improvement status of seed was negatively correlated with the presence of soil and water conservation structures in the plot (Table 7), suggesting that farmers tend to grow them on the plots that have less degraded land. This pattern makes sense if we imagine that the fields with the longer cultivation, where anti-erosion structures have been built, are where farmers plant their most "rustic," local varieties.

In Table 8, we present the household characteristics that we expect to be strongly related to the adoption of new techniques, technologies, and seed varieties. Despite the small numbers of hybrid growers in 2013 (45 EAFs), we see plainly that they are wealthier in terms of total value of assets and enjoy a larger number of economically active adults per household (10.5 as compared to 8.8). Thus, they are relative advantaged in terms of financial and human capital endowments. These findings are commonly reported in the broad literature on the adoption of agricultural technologies (Feder, Just and Zilberman 1985; Feder and Umali 1993: Foster and Rosensweig 2010). With respect to credit and other services, "encadrement" of the plot manager's village (membership in an organized cooperative structure) is greater among plot managers who grow sorghum hybrids, but the opposite is true for those who grow other improved varieties. This result suggests diffusion of older improved varieties from farmer to farmer beyond initial points of introduction by government programs. On the other hand, there is no clear relationship evident between whether or not the village hosts a weekly market fair and seed use by plot managers in the same village.

B. Ordered logit regression

The ordered logit regression model explaining the adoption of sorghum varieties by improvement status is shown in Table 9. Marginal effects are presented in Annex.

Plot manager characteristics, which reflect the social organization of farming in this region of Mali, are key determinants of variety adoption in sorghum production. These features are not often included in adoption studies, which usually focus on household characteristics. Individual management of a plot, compared to collective management of a plot, reduces the likelihood that improved varieties of sorghum are grown. Controlling for this factor, management by the wife of the head increases the chances that improved varieties, and especially hybrids, are grown in the plot; the effect of management by the son is also significant but weaker in magnitude and significance. Attainment of primary education by the plot manager is strongly significant for adoption of improved varieties, and even more so for sorghum hybrids. While plot location does not appear to play much of a role, erosion control structures on the plot (stone contour walls, contour bunds, living fences) are negatively associated with planting improved sorghum varieties or hybrids. This is consistent with the hypothesis that farmers plant their local varieties on more degraded soils. As in the broad adoption literature, capital endowments (household wealth and household labor supply) are strongly significant in predicting the use of improved sorghum varieties.

On the other hand, neither the extent of membership of village plot managers in a registered cooperative nor the presence of a weekly market fair in the village appears to influence the likelihood that improved varieties of sorghum are planted on a plot. The explanation for the first result is that registered cooperatives are primarily conduits for inputs and services related to cotton production, which also includes maize seed but not sorghum seed. Fertilizer subsidies, while facilitated by cooperatives, have also been facilitated by other associations and are in principle available to sorghum growers, though at a lower rate (Thériault et al. 2015). Improved sorghum seed has been introduced occasionally by external organizations and programs, but directly and indirectly via farmers' associations. However, diffusion has occurred primarily from farmer to farmer, among those who are members of farmers' associations, but not exclusively. Concerning the local market, it is still the case that little of the sorghum seed planted by farmers in this region passes through commercial markets or agrodealers, despite efforts by donors to stimulate the development of seed markets (Haggblade et al. 2015).

C. Multivalued treatment effects models

Estimates of Average Treatment Effects, expressed as means and percentages, are shown for all outcomes and the three modelling approaches in Table 10. In terms of significant effects, results are generally, but not always consistent across models. Of the three models, the AIPW and IPWRA is expected to be "doubly robust" and more efficient.

Signs and significant differ by outcome, and by improvement status of the sorghum variety. Yield effects are strongly significant and of a large relative magnitude for sorghum hybrids, but not for improved varieties, relative to local varieties. Yield advantages are between 479 and 1055 kg/ha, depending on the model, which represents 79% to 1.80% of the mean of the local varieties grown by farmers. This result confirms findings reported by Rattunde et al. (2013), which were generated by on-farm trials. Anecdotal evidence, and farmers' statements, suggest that yield advantages are hard to discern in farmers' fields with improved varieties, although these have many other advantages for farmers. Thus, we observe advantages of 35%, but these do not tend to be statistically significant in our sample of 734 plots.

The ATE on Household Dietary Diversity (HDDS) is not statistically significant in any of the three models, indicating that higher sorghum yields do not translate into a broader range of food groups consumed when measured as a simple count. Yet, when the frequency of consumption is taken into account, there is an impact on dietary diversity that is meaningful and significant for hybrid growers (and increase in the score of 7-8% in the AIPW and IPWRA models).

The impact of growing improved varieties or sorghum hybrids on the share of sorghum in cereals consumed is negative, by either measure (week prior to survey or harvest). Higher yields leads to the capacity to release land for other cereals or utilize earnings from sales to purchase them. Maize is both grown and consumed more than in the past, and urban consumers in particular have shifted from sorghum and millet toward maize and rice (Kelly et al. 2015).

Consistent with these points, the impact of growing improved varieties is positive on the share of other cereals consumed. At the same time, the share of the sorghum harvest sold rose by 10 to 14% depending on the models. Growing improved sorghum varieties thus contributes to commercializing a food crop for which no formally developed supply channel has been developed.

IV. Conclusions

In this analysis, we have contributed to a sparse literature on the adoption and impacts of improved sorghum varieties in Mali, also including the first sorghum hybrids released by the national program, which are based on Guinea-race germplasm and developed with participatory, on-farm trials. First, we used ordered logit model to identify determinants of adoption, which enabled us to differentiate between three ordered types of sorghum varieties: local (0), improved (1), and hybrid (2). Reflecting the social organization of sorghum production in the Sudanian Savanna of Mali, we tested the significance of plot manager characteristics, as well as plot, household and market characteristics in our regressions. Then, we applied a multivalued treatment effect approach to evaluate the impact of adoption of sorghum varieties and sorghum hybrids on farm families. In terms of outcomes, we evaluated both supply outcomes (yield) and consumption outcomes (dietary diversity, share of sorghum in consumption and sales). For robustness, we applied three statistical models.

We found that adoption varies by type of plot management characteristics and by gender of plot manager. Our data also shows that adoption varies between collectively-managed plots and individually managed plots; most individual sorghum plots are managed by women. There is continuous use of land under sorghum implying that land is scarce and poor in that part of the country. The cultivation of hybrid varieties is negatively correlated with soils and water conservation techniques. Consistent with a large literature on the topic, early adopters of new techniques (in our case, sorghum hybrids) are wealthier in terms of assets and human capital (household labor supply, education of the plot manager).

Bivariate results were generally borne out in the ordered logit regression model. Management of the plot by individual other than the head, the wife or son of the head, and attainment of primary education by the plot manager were significant factors, as were household capital endowments and the presence of anti-erosion structures on the plot. Our analysis found also that being a member of a cooperative or the presence of a weekly market fair in the village has no effect on adoption of improved sorghum varieties because cooperatives facilitate mainly access to fertilizer and other credits to members; while seeds are mostly not traded in the market but passes form farmer to farmer.

The multivalued treatment effects model shows that Yield effects are strongly significant and of a large relative magnitude for sorghum hybrids, but not for improved varieties, relative to local varieties. Yield advantages are between 479 and 1055 kg/ha, depending on the model, which represents 79% to 1.80% of the mean of the local varieties grown by farmers. The ATE on Household Dietary Diversity (HDDS) is not statistically significant in any of the three models, indicating that higher sorghum yields do not translate into a broader range of food groups consumed when measured as a simple count. Yet, when the frequency of consumption is taken into account, there is an impact on dietary diversity that is meaningful and significant for hybrid growers (and increase in the score of 7-8% in the AIPW and IPWRA models). The impact of growing improved varieties or sorghum hybrids on the share of sorghum in cereals consumed is negative, by either measure (week prior to survey or harvest). The impact of growing improved varieties is positive on the share of other cereals consumed. At the same time, the share of the sorghum harvest sold rose by 10 to 14% depending on the models.

V. Implications for policy and future research

The analyses presented here permit us to draw several implications of relevance to national policy in Mali. First, we find that sorghum variety adoption is potentially higher on plots managed by individuals, and especially women, within the extended family. Harvests from these smaller plots enable women to address the nutritional needs of their children and meet the costs of clothing, school, and health care. Any policy aiming to promote the development and diffusion of improved varieties of sorghum (especially hybrids) should now recognize the potential role of women members of the farm family enterprise in planting and producing sorghum. This pattern is clearly a change in cultural norms; the conventional wisdom has been that women were not involved in sorghum production outside the collective fields of the family.

Second, generally speaking, the characteristics of the plot manager, in addition to the plot and household characteristics, are strong determinants of variety and hybrid adoption in sorghum production. Market access and access to cooperative structures do not yet seem to be as important, although this may change as sorghum production commercializes. To encourage higher adoption rates, our results indicate that channels of introduction for seed and complementary inputs such as fertilizer should incorporate not only the household head but also all economically active members of the EAF.

Third, the impact analysis confirms the major yield impacts of hybrid seed on yields, as reported in previously published results based on data from on-farm trials. We also observe an impact on household dietary diversity when the frequency of consumption is considered. We see that the share of the harvest sold increases when hybrids are grown, suggesting that households have the choice of expanding their consumption purchases. When yields rise, land is also released for the production of other crops. In this way, hybrid production could contribute to a more commercial orientation of production for some growers. In order to facilitate the expansion of yield and revenue benefits more widely among smallholder sorghum growers in Mali, the constraints to hybrid seed multiplication, production and distribution should be addressed.

In terms of technical aspects of future research, further calibration of these results with detailed soils data in the yield outcome model and enhanced measures of dietary diversity in the consumption model may prove informative. Some sensitivity analysis on model results might shed light on the high-end values we obtain in some of the yield models. As another robustness check, it may be helpful to test binary impacts with improvement categories taken two at a time.

More importantly, concerning substantive issues, testing these results in other regions and crops will be important for national policy. Should the findings concerning plot management be borne out in other studies conducted on other crops and other regions, they would underscore the need to reconsider the design of conventional extension approaches.

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Table 1. Adoption model explanatory variables, definitions and means

Explanatory variable	Definition
plot manager characteristics	
individually-managed	plot managed individually by male who is not the EAF head or designate=1, else 0
education	plot manager attended primary school=1, 0 else
wife	plot manager is wife of the head of EAF =1 , 0 else
son	plot manager is son of the head of EAF =1, 0 else
plot characteristics	
location	time in minutes to travel from home to the plot
erosion control	any anti-erosion structure built on plot=1, 0 else
household characteristics	
assets	total value of household assets, excluding livestock (ln FCFA)
labor supply	number of adults in EAF between 12 and 55 years of age (inclusive)/total area operated by EAF
market characteristics	
cooperative	share of plot managers in village who are coop members
market	weekly market fair in village=1, 0 else

Source: Authors.

Table 2. Impact model control variables, definitions and means

Control variable	Definition
production inputs	
seed	quantity of seed used
fertilizer	total kgs of fertilizer applied
male labor	number of adult male person-days (14 years and above)
female labor	number of adults female person-days (14 years and above)
child labor	number of children person-days (under 14 years)
plot characteristics	
location	time in minutes to travel from home to the plot
erosion control	any anti-erosion structure built on plot=1, 0 else
plot manager characteristics	
education	plot manager attended primary school=1, 0 else
wife	plot manager is wife of the head of EAF =1 , 0 else
son	plot manager is son of the head of EAF =1, 0 else
consumption factors	
market	weekly market fair in village=1, 0 else
household size	number of EAF members
transfers	income from absent household members in previous 12 months
assets	total value of household assets, excluding livestock (ln FCFA)

Source: Authors

Table 3. Impact model outcome variables, definitions and means, by treatment

Outcome	Definition	Local variety	Improved variety	Hybrid variety
yield	sorghum kgs harvested/ha (GPS)	782.4	873.9	994.6
hdds	Household Dietary Diversity Score (HDDS); see text	7.44	7.47	7.78
freqhdds	Household Dietary Diversity Score (HDDS) with frequency of consumption; see text	11.8	11.8	12.7
sorghum share	value share of sorghum in consumption expenditures during 7 days before survey	0.075	0.0841	0.00536
sorghum share1	quantity share of sorghum in cereals consumed during crop season	0.38	0.322	0.364
partcereal	value share of other cereals in consumption expenditures during 7 days before survey	0.266	0.285	0.39
sharesold	share of sorghum harvest sold	0.0591	0.113	0.179

Source: Authors. N=730 plots, 623 EAFs.

Table 4. Sorghum variety adoption by plot management

		Sorghum variety			
		Local	Improved	Hybrid	All varieties
Gender of plot manager					
	Male	328	174	36	538
		60.97	32.34	6.69	100
	Female	106	78	9	193
		54.92	40.41	4.66	100
Management type					
	Collective plot	322	171	36	529
		60.87	32.33	6.81	100
	Individual plot	112	81	9	202
		55.45	40.1	4.46	100

Source: Authors. Pearson chi2(2) = 4.5083 Pr = 0.105; 4.5982 Pr = 0.100

Table 5. Sorghum variety adoption, by relationship of plot manager to head

	Sorghum variety			
	Local	Improved	Hybrid	All varieties
Other family members	352	186	36	574
	61.32	32.4	6.27	100
Wife of head	82	66	9	157
	52.23	42.04	5.73	100
Total	434	252	45	731
	59.37	34.47	6.16	100
	Pearson chi2(2) = 5.0949 Pr = 0.078			
	Locale	Ameliore	Hybride	Total
Other family members	395	217	39	651
	60.68	33.33	5.99	100
Son of head	39	35	6	80
	48.75	43.75	7.5	100
Total	434	252	45	731
	59.37	34.47	6.16	100
	Pearson chi2(2) = 4.2128 Pr = 0.122			

Source: Authors.

Table 6. Sorghum variety adoption, by education of plot manager

	Attained a primary education		All
	No	Yes	
Local variety	388	46	434
	89.4	10.6	100
Improved variety	195	57	252
	77.38	22.62	100
Hybrid variety	34	11	45
	75.56	24.44	100
Total	617	114	731
	84.4	15.6	100

Pearson chi2(2) = 20.3520 Pr = 0.000

Table 7. Soil erosion structure on plot?

	No	Yes	Total
Local	346	88	434
	79.72	20.28	100
Improved	216	36	252
	85.71	14.29	100
Hybrid	42	3	45
	93.33	6.67	100
All sorghum varieties	604	127	731
	82.63	17.37	100

Source: Authors. Pearson chi2(2) = 6.5960 Pr = 0.037

Table 8. Sorghum variety adoption, by household and village market characteristics

	Grow sorghum hybrids			Grow improved varieties		
	No	Yes	p-value	No	Yes	p-value
Total value of EAF assets (ln)	13.9	14.3	0.0437	13.9	14.1	0.0221
Number of EAF active adults (12 to 55 years)	8.80	10.5	0.0418	8.35	9.56	0.0032
Proportion of plot managers in village who belong to a cooperative	37.5	45.2	0.0428	40.1	32.9	0.0002
Presence of market fair in village						
No market	541	37	578	373	205	578
	93.6	6.4	100	64.53	35.47	100
Market	145	8	153	106	47	153
	94.77	5.23	100	69.28	30.72	100
	Pearson chi2(1) = 0.2880 Pr = 0.592			Pearson chi2(1) = 1.2074 Pr = 0.272		

Source: Authors. Note that comparison group for hybrid growers in this table includes both improved and local varieties.

Table 9. Ordered logit model explaining sorghum variety adoption

	Improvement status
individually-managed	-0.573*
	(0.327)
wife	0.882**
	(0.344)
son	0.407*
	(0.240)
education	0.878***
	(0.204)
location	0.00207
	(0.00363)
erosion control	-0.475**
	(0.204)
assets	0.206***
	(0.0785)
labor supply	0.191**
	(0.0826)
cooperative	-0.0147
	(0.353)
market	-0.154
	(0.197)
Constant cut1	3.605***
	(1.143)
Constant cut2	6.049***
	(1.148)
Observations	728

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Improvement status: 0=local variety; 1=improved variety; 2=hybrid variety

Table 10. Average treatment effects, by outcome and model

		RA		AIPW MNL		IPWRA MNL	
		coef	p-value	coef	p-value	coef	p-value
yield	ATE						
	improved	203.8		173.0		204.3	
	Hybrid	478.5**		779.4**		1054.8***	
	ATE %						
	improved	.3357052	0.300	.2275826	0.304	.3486967	0.333
	hybrid	.7880124	0.003	1.025119	0.011	1.8005	0.001
hdds	ATE						
	improved	0.278		-0.0680		-0.0548	
	Hybrid	0.418		0.255		0.243	
	ATE %						
	improved	.0423875	0.279	-.0091213	0.571	-.0073566	0.628
	hybrid	.0637822	0.451	.0341591	0.135	.032652	0.147
freqhdds	ATE						
	improved	0.388		-0.0915		-0.0873	
	Hybrid	1.207		0.841**		0.903**	
	ATE %						
	improved	.0369894	0.364	-.0077307	0.694	-.0073753	0.706
	hybrid	.1150511	0.215	.0710718	0.024	.0762431	0.010
sorghum share	ATE						
	improved	0.000373		-0.00828		-0.00725	
	Hybrid	-0.0679***		-0.0694**		-0.0699***	
	ATE %						
	improved	.0053511	0.979	-.1082744	0.567	-.0946649	0.602
	hybrid	-.9744761	0.000	-.9076069	0.014	-.9125638	0.000
sorghum share1	ATE						
	improved	-0.0363		-0.0734**		-0.0720**	
	Hybrid	0.0120		-0.00288		-0.00522	
	ATE %						
	improved	-.1126063	0.193	-.1902753	0.005	-.1867071	0.004
	hybrid	.0373155	0.865	-.0074596	0.964	-.0135241	0.919
partcereal	ATE						
	improved	0.0456*		0.0646*		0.0592*	
	Hybrid	0.0202		0.0542		0.0625	
	ATE %						
	improved	.1835128	0.091	.2393542	0.108	.2194374	0.087
	hybrid	.0811734	0.668	.2009184	0.318	.2316561	0.200
sharesold	ATE						
	improved	0.0522**		0.0811**		0.0760**	
	Hybrid	0.142***		0.104**		0.105**	
	ATE %						
	improved	.937192	0.025	1.242769	0.044	1.166684	0.026
	hybrid	2.556126	0.002	1.601737	0.035	1.614431	0.030

* p<0.10, ** p<0.05, *** <0.001

Annex Table 1. Predicted marginal effects, ordered logit model

	dy/dx	Delta-method Std. Err.	z	P>z
Individually-managed plot				
local variety	0.13004	0.073798	1.76	0.078
improved variety	-0.09757	0.055008	-1.77	0.076
hybrid variety	-0.03247	0.019407	-1.67	0.094
Wife				
local variety	-0.20016	0.077019	-2.6	0.009
improved variety	0.150182	0.057427	2.62	0.009
hybrid variety	0.049976	0.020973	2.38	0.017
Son				
local variety	-0.09246	0.05413	-1.71	0.088
improved variety	0.069376	0.040743	1.7	0.089
hybrid variety	0.023087	0.013827	1.67	0.095
Education				
local variety	-0.19928	0.044414	-4.49	0.000
improved variety	0.149523	0.033556	4.46	0.000
hybrid variety	0.049757	0.013174	3.78	0.000
Anti-erosion				
local variety	0.107774	0.045797	2.35	0.019
improved variety	-0.08086	0.033982	-2.38	0.017
hybrid variety	-0.02691	0.012477	-2.16	0.031
Assets				
local variety	-0.04677	0.017592	-2.66	0.008
improved variety	0.035094	0.013091	2.68	0.007
hybrid variety	0.011678	0.004828	2.42	0.016
Labor supply				
local variety	-0.04325	0.018644	-2.32	0.02
improved variety	0.032448	0.014146	2.29	0.022
hybrid variety	0.010798	0.004777	2.26	0.024

* only statistically significant variables are included
n=728