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Testing Theories of Change for Dryland Cereals: The HOPE project in central Tanzania 2009-2012

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Abstract

The Harnessing Opportunities for Productivity Enhancement (HOPE) project was based on a market-led Theory of Change in which farmers adopted new technology for sorghum and millets in response to market demand. This Theory of Change was tested using panel survey data for 360 farm households in central Tanzania covering the crop seasons 2009/10 and 2011/12. Because improved varieties of finger millet were unavailable in 2009, the analysis focused primarily on sorghum. Propensity score matching was used to obtain a matched sample of treatment and control households, which were compared to estimate the unconditional impact of the project, augmented by regression analysis using the matched samples to obtain robust results. HOPE significantly increased the probability of knowing at least one improved sorghum variety by 9.5 %, and the share of farmers adopting improved varieties of sorghum by 13.2 %. However, HOPE had no significant positive impact on the area, yield, and output of sorghum, or improve farmers' technical efficiency in producing sorghum. HOPE did not increase the use of commercial channels for the supply of improved seed. Finally, HOPE increased neither the commercialization of sorghum, which remained primarily a food crop, nor of finger millet, which was already a cash crop before the start of the project. These findings show that enhancing productivity for dryland cereals requires not just improved varieties but also improved crop management, and that adoption of improved varieties is not driven exclusively by market demand but by the need for household food security. These findings also challenge the relevance of a universal Theory of Change for dryland cereals in Eastern and Southern Africa. Finally, they highlight the need for a revised Theory of Change that reflects the diversity of farmers' objectives in growing these crops and of market opportunities within the region.

Keywords: Impact analysis, Theory of change, commercialisation, sorghum, millets

JEL classification: O13, O22, O33, Q12

Contents

List of Tables

List of Figures

List of Tables in Appendix

Acronyms

ALINe	Agricultural Learning and Impacts Network
APSIM	**Agricultural Production Systems Simulator**
ATT	Average Treatment Effect on Treated
BMGF	Bill and Melinda Gates Foundation
DRD	Department of Research and Development
ESA	Eastern and Southern Africa
FFS	Farmer Field School
HOPE	Harnessing Opportunities for Productivity Enhancement
ICRISAT	International Centre for Research in the Semi-arid Tropics
OPV	Open Pollinating Variety
QDS	Quality Declared Seed
SSP	Small Seed Pack
TZS	Tanzanian Shillings

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1. Introduction

'It should be mandatory that when projects end they should have changed their Theory of Change'. Robert Chambers 1

Agricultural research and development projects are a rich source of learning about Theories of Change. Like all projects, they focus on change: why change is needed, what has to change, and how to change behavior. Inevitably, however, some initial assumptions underlying Theories of Change prove mistaken, sometimes for reasons that could not be known in advance. Theories of Change may themselves change during implementation. Indeed, a core function of project monitoring and evaluation is to learn from the mistakes in the original Theory of Change. Changing the Theory of Change then becomes a learning outcome that can be used to improve the design of future projects.

This study tests the Theory of Change for Harnessing Opportunities for Productivity Enhancement (HOPE) of sorghum and millets in Sub-Saharan Africa and South Asia, a project funded by the Bill & Melinda Gates Foundation (BMGF). The goal of the project was to increase productivity in order to increase household income from these crops and reduce poverty (ICRISAT, 2009). During the four years of the project (2009-2013),[2] 50,000 households in Eastern and Southern Africa (ESA) were expected to benefit. By the end of the project, the adoption of improved varieties in the project areas was expected to reach 50 % of the area planted to sorghum and millets, while the average yield of sorghum was expected to rise by 35% from 1.32 to 1.78 t ha^{-1} and the average yield of finger millet by 56% from 0.5 tons to 0.78 tons ha^{-1} (ICRISAT, 2009: Annex 1).

HOPE hypothesized that the adoption of new technology was driven by market demand, and that higher yields would increase cash incomes by allowing commercialisation. The general objective of this paper is to test this market-led Theory of Change for dryland cereals in Eastern and Southern Africa. The specific objectives are to test the null hypotheses that the HOPE project had no impact on:

1. Awareness of improved varieties;
2. Adoption of improved varieties;
3. Area, yield and output of dryland cereals;
4. Use of commercial seed channels; and
5. Commercialisation of dryland cereals.

One limitation of this study is the short period – three years – for which data is available. It may be objected that this is too short a time for a fair test of any theory of change. Certainly, impacts on household welfare would require a longer period to evaluate. Nevertheless, three years gave sufficient time to evaluate the process of change that was expected to deliver

[1] Comment at the annual conference of the United Kingdom Development Studies Association, London, November 2012.

[2] The official start and end dates were as 1 July 2009 and 30 June 2013. A no-cost extension took HOPE Phase 1 up to 30 June 2014.

those impacts. This paper focuses on the intermediate results that were essential for the project to meet its longer-term goals. A further limitation is that the paper is based on quantitative survey data that is not triangulated with evidence from other sources, including the farmers who participated in the project. This gives a simplistic picture of rural society being shaped by the 'impact' of new technology, whereas farmers actively adapt new technology to suit their conditions. Their views on HOPE's Theory of Change would have made interesting reading.

The rest of this discussion paper is organized as follows. The next section describes the Theory of Change for the HOPE project. Section 3 describes the methodology used to test this Theory of Change. The fourth Section presents the results, which are discussed in Section 5. The last Section concludes.

2. Theoretical framework

2.1 HOPE's meta-narrative

'Theories of Change are often based on weak and selective evidence bases. This can allow them to reinforce and mask the problem they aim to resolve'. (Valters, 2015: 6).

The proposal for the HOPE project did not include a formal Theory of Change. However, it did contain a meta-narrative that explained the thinking behind the design of the project. HOPE used an 'integrated value chain approach' in which the adoption of new technology was driven by market demand. The rationale for this approach was that the model of the Green Revolution in South Asia was not relevant for semi-arid agriculture. In the words of the project document:

> '*This model of intensive high-yield agriculture was very successful where it was possible to minimize natural resource constraints, e.g. through irrigation and large applications of fertilizers, providing homogeneous, low-stress, high-yielding conditions for crop. However, this approach has been less successful for crops and farming systems in rainfed dryland environments where irrigation is impractical and natural resource constraints are more difficult to alleviate.*
>
> *Given the stresses and variability of the rainfed drylands, a different approach is needed - one that adapts to environmental variability and risks, rather than assuming that homogenization will occur… Increasing grain production, though, is not enough. Experience shows that bumper yields of dryland crops soon create a glut on the market, because market outlets for these crops have stagnated or declined. As a result of these two dynamics – lack of adaptive approaches to raise productivity combined with shrinking markets – dryland farmers found themselves unable to profit by investing in commercial production….*
>
> *Overcoming dryland Africa's stagnant food production trend requires the growth, expansion and diversification of markets for dryland crops, so that farmers will be rewarded for increasing their production and productivity. In recent years, major*

> *new trends towards increasing demand for dryland cereals have begun to emerge that provide a renewed opportunity for sorghum and millets in the marketplace.* ***The main thrust of this Project is to provide poor dryland households with the technologies, linkages, and development impetus they need to harness the "pull" of these growing markets'.*** (ICRISAT, 2009: 1-2: emphasis in original).

This rationale became the basis for the project hypothesis:

'*The combination of improved technologies (crop varieties and management) with institutional innovations that increase market access and demand will drive adoption and increase production of sorghum and millets in sub-Saharan Africa and South Asia. This will improve household food and nutritional security and facilitate transition to market-oriented and viable sorghum and millet economies that enhance livelihoods of the poor'.* (ICRISAT, 2009: 5).

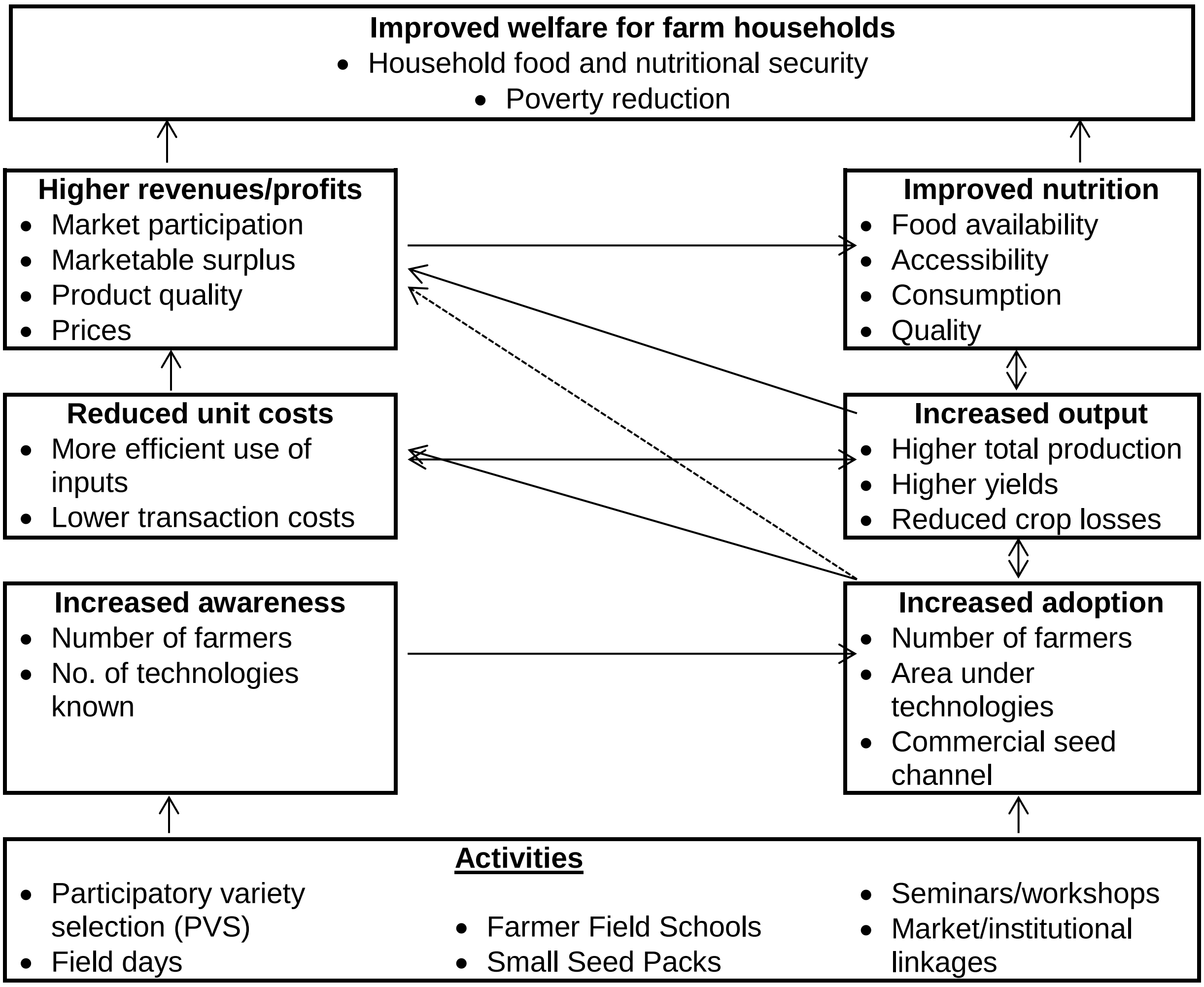
This meta-narrative was based on two types of evidence: first, the potential yield advantage from 'integrated crop management' (combining improved varieties and crop management practices) and, second, the growth in market demand for dryland cereals, namely for livestock feed, for value-added products from affluent urban consumers, and as food for the growing population in areas where sorghum and millets were grown (ICRISAT, 2009: 3-4). However, the project proposal presented no evidence on (1) widespread farmer *adoption* of integrated crop management (2) the competitiveness of sorghum and millets as sources of livestock feed outside India, and on the scale of demand from urban, middle-class consumers. In the absence of this evidence, the meta-narrative for HOPE was largely supposition. Assumptions (that large numbers of farmers would adopt integrated crop management and the existence of large, untapped markets for dryland cereals) were being taken as facts.

HOPE's 'integrated value chain approach' was equally problematic since in some areas markets for dryland cereals did not exist. In the absence of these markets, the proposal argued that 'the whole value chain from input supplies through production to output markets will need to be built' (ICRISAT, 2009: 4). In retrospect, this was over-ambitious. Earlier analyses of market opportunities in ESA were more cautious. Rather than creating markets from scratch, 'we should be offering technological solutions capable of improving the efficiency of product markets where commercial interest and/or investment is already strong' (Alumira and Heinrich, 2003: 14). A more realistic objective would have been for HOPE to target and support existing markets.

2.2 HOPE's Theory of Change

There is no agreed definition of a Theory of Change (Stein and Valters, 2012). Some define it in programmatic terms: '*A theory of change describes the types of interventions that bring about the outcomes depicted in the outcomes framework map. Each intervention is tied to an outcome in the causal framework, revealing the often complex web of activity required to bring about change*' (Taplin and Clark, 2012). Others define theories of change not as a product but as a process: *'A Theory of Change is an ongoing process of reflection to explore change and how it happens – and what that means for the part we play in a particular* *context, sector and/or group of people'* (Valters, 2015). Since our objective is to test causal links in the Theory of Change against evidence from impact analysis, this paper adopts a programmatic perspective, but the findings may also inform the wider process of changing HOPE's Theory of Change. Based on the meta-narrative, we can reconstruct a generalized theory of change for the HOPE project showing the hypothesized causal links between the project's activities, outputs and outcomes (Figure 1).

Figure 1: A generalized Theory of Change for the HOPE project 2009-2014



Source: Authors

Activities: Project activities to popularise HOPE technologies included participatory variety selection (PVS), field days, Farmer Field Schools (FFS), seminars and workshops, the distribution of Small Seed Packs (SSPs), and linking farmers with grain buyers and input suppliers.

Results: These activities were hypothesized to produce three major results:

1. Greater farmer awareness would result in higher adoption of improved varieties and crop management technologies;

2. Higher demand for improved seed would create market opportunities for commercial seed suppliers; and
3. Improved varieties and crop management would result in reduced unit costs and higher yields.

Outcomes: Higher yields were hypothesized to increase farmers' ability to participate in output markets and to increase the quantity of sorghum and millet they sold, thereby increasing cash income. Increased output was also expected to improve household nutrition by increasing household food security. With higher income and improved nutrition, overall welfare was expected to improve in the long run.

3. Methodology

3.1 Data

3.1.1 Baseline Survey

HOPE conducted a baseline survey of 360 farm households Kondoa and Singida Rural Districts, central Tanzania. In each district, 90 households were classified as 'treatment' households located in villages that were the focus of project activities; 45 were classified as 'diffusion' households in villages adjacent to the 'treatment' villages; and 45 were classified as 'control' households located in villages that were far from either 'treatment' or 'diffusion' villages so that spill-over effects were minimized. The logic was to group villages that were close geographically and shared the same agricultural extension officer into one 'village cluster'. Respondents were then randomly selected from each village within a cluster using lists provided by village administrators. The survey was conducted in August 2010, after the harvest of the crop planted in November 2009. The data covered the crop season 2009-2010 (Schipmann et al. 2013).

3.1.2 Early-adoption survey

HOPE funded an early-adoption survey that re-surveyed the baseline households. The early-adoption survey located and re-interviewed 346 of the original 360 baseline survey households. The survey was conducted in August 2012, after the harvest of the crop planted in November 2011. The survey covered the crop year 2011-2012 (Muange, 2015).

3.1.3 Panel data

Together the two surveys provide an opportunity to measure changes in various outcomes for sorghum and millets as the result of project activities over three crop seasons (2009/10, 2010/11 and 2011/12) between the years 2009 and 2012.

Table 1 shows the sample size by village cluster in each district and by survey round. To simplify the presentation of results, the diffusion and control clusters were re-categorized as one control group, which also gives a bigger sample size that is comparable to the treatment group. Detailed results comparing changes in the three separate clusters are provided in Appendix 1.

Table 1: Sample for baseline and follow-up surveys stratified by village cluster

Village cluster	Baseline (2010)			Early-Adoption (2012)		
	Kondoa	Singida Rural	Total	Kondoa	Singida Rural	Total
Treatment	90	88	180	90	83	171
Diffusion	45	45	90	45	43	88
Control	45	42	90	45	45	87
Total	180	175	**360**	180	171	**346**

Source: HOPE baseline and early-adoption surveys.

The data was collected through face-to-face interviews with heads of the sample households using a pre-tested structured questionnaire, and administered by enumerators supervised by ICRISAT and the Ministry of Agriculture's Division of Research and Development (DRD), Central Zone, Tanzania.

Table 2: Variable definitions and descriptive statistics

Variable	Definition/measurement	Baseline		Early Adoption	
		Mean	SD	Mean	SD
Female	Respondent is female (0=No, 1=Yes).	0.14	0.35	0.27	0.44
Age	Age of respondent (years).	44.6	11.5	46.1	11.4
Farmexpr	No. of years since respondent started farming	22.2	10.9	25.3	11.3
Sorgexpr	No. of years since respondent started sorghum farming	18.7	12.6	20.7	12.7
Education	Education of respondent (0< 4 years, 1=4 years or more.	0.83	0.38	0.83	0.37
Muslim	Respondent is a Muslim (0=No, 1=Yes).	0.56	0.50	0.57	0.50
Hhsize	Number of household members.	6.49	2.27	6.42	2.45
Fem1564	No. of female household members aged 15-64 years.	1.54	0.95	1.45	0.87
Mal1564	No. of male household members aged 15-64 years.	1.74	1.11	1.70	1.09
Ownland	Land owned by household (Ha).	4.83	8.13	4.40	5.70
Cultland	Land cultivated by household (Ha).	2.73	2.82	2.72	2.30
Livestock	Value of livestock owned (TSh million[3]).	4.37	10.1	2.16	3.45
Association	Household head/spouse is a member of a community group or association (0=No, 1=Yes).	0.31	0.46	0.29	0.45
Radio	Household owns a radio (0=No, 1=Yes).	0.81	0.39	0.75	0.43
Mobile	Household owns a mobile phone (0=No, 1=Yes).	0.49	0.50	0.70	0.46
Plough	Household owns an ox-plough (0=No, 1=Yes).	0.24	0.43	0.62	0.49
Bicycle	Household owns a bicycle (0=No, 1=Yes).	0.61	0.49	0.32	0.47
Infonet	Information network degree (No. of other farmers from the village cluster that the respondent talks to).	2.92	1.58	2.92	1.58
Adminlink	Frequency of communication with a member of the village administration (days/month).	13.8	9.57	13.8	9.67

Note: SD= standard deviation.

[3] The official exchange rate for the US dollar was approximately 1,470 and 1,560 Tanzanian Shillings (TZS) during the baseline and early-adoption surveys, respectively.

Unlike the HOPE baseline, the early-adoption survey did not collect information on household expenditure, hence changes in household income could not be analyzed. Moreover, whereas the improved sorghum varieties Pato and Macia promoted by HOPE were released in 1195 and 1999, respectively (Monyo et al. 2004) the improved finger millet varieties U15 and P224 were not officially released in Tanzania until 2011. Therefore, comparisons between sorghum and finger millet could not be made for all hypotheses. A description of the key variables used in this report and their mean values is provided in Table 2.

3.2 Methods

3.2.1 Propensity score matching

Estimating project impacts requires the establishment of an explicit counterfactual which shows what the outcome of interest would have been for the project participants in absence of the project (Ravallion, 2008). The ideal case would be an experiment in which households are randomly assigned to treatment (the group in which project activities would be carried out) or control (group without project activities) and then to estimate impact as the difference in the mean values of outcome variables between the two groups following project implementation (Baker, 2000). However, this is not always possible in development projects. For HOPE, a quasi-experimental design was used in which village clusters were assigned to treatment and control groups. However, closer examination of the data shows that this assignment was not necessarily random. Table 3 shows that treatment and control village clusters differed significantly with respect to sorghum and millet cultivation. The treatment villages had significantly lower proportions of sorghum and pearl millet growers, plus less area planted to these crops, than control villages. However, finger millet cultivation was significantly higher in the treatment villages. Similarly, in the unmatched sample, households in treatment and control groups differed significantly with respect to some socioeconomic characteristics such as religious affiliation, membership of community groups or associations, the size of their information network, and livestock wealth (Table A1).

Table 3: Comparison of baseline sorghum and millet cultivation statistics between treatment and control households

Variable	Definition/measurement	Treatment	Control
Sorghum grower	Proportion of sorghum growers (% sample)	61.7 (48.8)	78.9*** (40.9)
Finger millet grower	Proportion of finger millet growers (% sample)	82.8 (37.9)	58.9*** (49.3)
Pearl millet grower	Proportion of pearl millet growers (% sample)	39.4 (49.0)	58.3*** (49.4)
Sorghum area	Area planted to sorghum (ha)	0.48 (0.77)	0.75*** (1.37)
Finger millet area	Area planted to finger millet (ha)	0.86 (1.93)	0.49*** (0.85)
Pearl millet area	Area planted to pearl millet (ha)	0.31 (0.53)	0.45** (0.75)

Note: Figures are mean values, with standard deviations in parenthesis. *, **, *** differences between treatment and control groups are significant at 10%, 5% and 1% respectively, using t-test for continuous variables and z-test for proportions.

To control for possible selection bias and obtain a robust counterfactual, we used the propensity score matching (PSM) approach popularized by Rosenbaum and Rubin (1983). The approach involved four stages. First, estimating a propensity score (i.e., the probability that a household is included in the treatment group, given its baseline characteristics) using a logit regression; second, matching the treatment and control groups using an appropriate algorithm (Caliendo and Kopeining 2008); third, using t-tests to confirm that observable characteristics did not differ significantly between the matched treated and control groups; and lastly, applying the Rosenbaum bounding procedure to check the sensitivity of the matching results to unobservable characteristics that may have influenced the assignment of households into HOPE or non-HOPE project areas (DiPrete and Gangl, 2004).

Results for the model used to estimate the propensity score are shown in Table 4. The model indicates that the probability of a household to be included in HOPE increased with household head's age, if the head was a Muslim, and if the household had more members, owned a mobile phone or had stronger links with a member of the village administration. Wealthier households (proxied by value of livestock owned), those belonging to a community group/association and those with larger information networks were less likely to be selected for the HOPE project. This indicates that HOPE may have targeted poorer farmers who also tended to be older, with larger families, and less connected to other farmers in their villages. Such selection criteria are not uncommon in rural development projects. Similarly, the positive association between household links with village administrators and selection into the HOPE project is not surprising since these administrators play a key role in mobilizing farmers to participate in agricultural extension programmes and identifying project beneficiaries.

Table 4: Logit regression model for estimating propensity score

Variable	Coefficient	Variable	Coefficient
Age	0.024**	Mobile	0.582**
	(0.011)		(0.273)
Female	0.366	Association	-0.903***
	(0.355)		(0.266)
Muslim	1.287***	Infonet	-0.211***
	(0.291)		(0.079)
Hhsize	0.097*	Adminlink	0.030**
	(0.058)		(0.012)
Livestock	-0.202*	Kondoa	-0.486
	(0.109)		(0.310)
Bicycle	0.063	Constant	-1.650**
	(0.293)		(0.746)
Plough	-0.110	*N*	345
	(0.324)	pseudo R^2	0.116
Radio	-0.346	Mean propensity score	0.496
	(0.322)		(0.194)

Note: Robust standard errors (standard deviation for propensity score) in brackets; * p<0.1, ** p<0.05, *** p<0.01

Using the estimated propensity scores, five different matching algorithms were used to perform the PSM. These included nearest neighbor matching (1-1) without replacement, and with replacement using 1, 3 and 5 neighbors. The fourth algorithm was nearest neighbor (1-1), within a 0.2 caliper radius, and the fifth was kernel matching. Table 5 show that the algorithm that achieved the largest reduction in mean and median biases (about 81% and

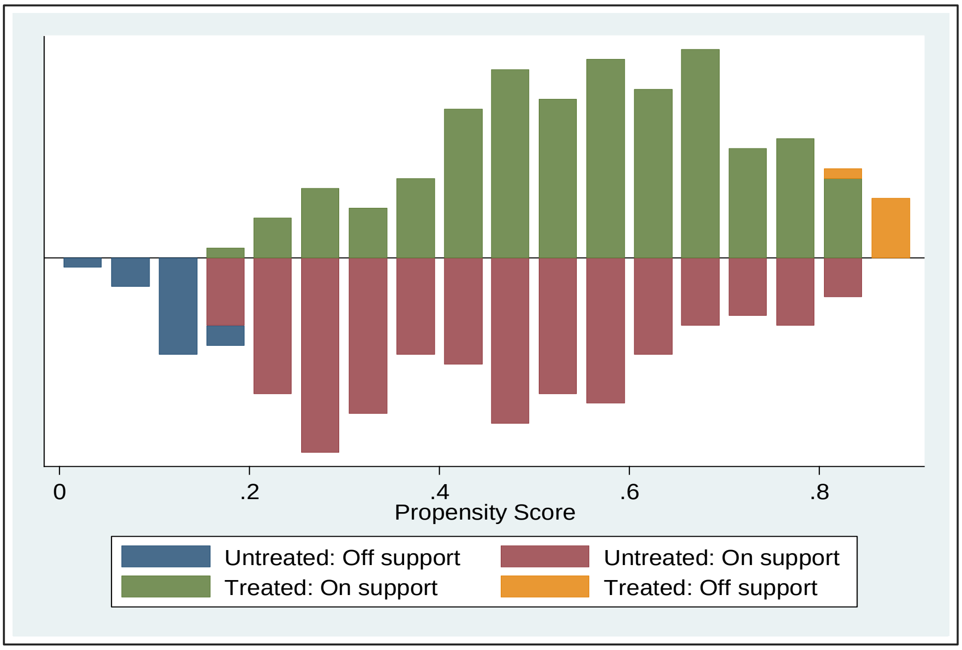
86% respectively) was kernel matching. The critical gamma at the 10% level was 3.7, implying that if there was an unobserved variable that was associated with selection into HOPE, then its value would have to increase almost four-fold to invalidate our results. With all five algorithms, sufficient common support was achieved, and the resulting matched sample was 322 (164 treated and 158 untreated) households. Distribution of the propensity score from kernel matching illustrated in Figure 2 shows a good balance of the score between treated and control groups, and sufficient common support. The sample from kernel matching was therefore used for the impact analysis in the next sections. Detailed information on covariate balancing and biases before and after matching is shown in Table A1.

Table 5: Matching results using different algorithms

Statistic	Raw sample	Matched sample, algorithms					
		NN1-without	NN1	NN3	NN5	NN Radius	Kernel
Pseudo R^2	0.117	0.081	0.027	0.012	0.006	0.010	0.004
LR chi^2	55.82	36.68	12.25	5.30	2.79	4.46	1.85
$p>chi^2$	0.000	0.000	0.508	0.968	0.999	0.985	1.000
Mean Bias	15.9	12.2	7.7	4.4	3.3	4.0	3.1
Median Bias	15.5	10.8	7.3	3.3	2.6	3.8	2.1
Rosenbaum bounds (critical γ)		1.5	2.1	2.7	2.7	4.3	3.7
Treated, on support (n)		164	164	164	164	164	164
Control, on support (n)		158	158	158	158	158	158

Note: NN1-without= nearest one neighbor without replacement; NN1, NN3, NN5 = nearest 1, 3 and 5 neighbors respectively, with replacement; NN Radius = nearest neighbor (radius with caliper=0.2). Critical γ= value at which γ (log odds of differential assignment due to unobserved factors) becomes insignificant at 10% level of significance.

Figure 2: Distribution of propensity score showing common support



3.2.2 Difference-in-differences

HOPE was expected to have impacts on the cultivation of sorghum and millets, awareness and adoption of improved varieties, and productivity of these crops. Hence, following the construction of treatment and control groups, the data were analyzed by comparing sample means of these outcomes between the treated and control groups at baseline (before HOPE started) and follow-up (three years after HOPE started). This formed the unconditional average treatment effect on the treated (ATT), which is popularly known as difference-in-differences or double-difference (Angrist and Pischke, 2008).

Following Cameron and Trivedi (2005), the treatment effect was estimated using the equation:

$$ATT = [E(y_{ie} - y_{ib})|H_{ie} = 1] - [E(y_{ie} - y_{ib})|H_{ie} = 0] \quad (1)$$

where ATT is the average treatment effect on the treated (i.e., HOPE impact in project villages); E is the expected value (mean); y is the outcome of interest, i represents individual farmer; b and e represent baseline and early-adoption surveys respectively; and H is the treatment status (residing in a HOPE project village).

This approach recognizes that treatment and control groups may differ in the post-treatment survey due to permanent differences between the two groups, as well as other time-variant factors that are not associated with the project. Hence, subtracting the changes in mean outcomes for the control group from the changes in mean outcomes for the treated group gives a measure of project impact that excludes the confounding effects of time trends.

3.2.3 Regression analysis

To introduce robustness in the estimated impacts, regression-based methods were also employed, which control for impacts of other (farmer and environmental) variables on the outcome variables. The general regression framework for crop cultivation and improved variety awareness and adoption was:

$$Y_{it} = \lambda_0 + \boldsymbol{x_{it}\lambda} + \gamma_1 Round2_t + \gamma_2 Hope_i + \gamma_3 (R2_t * Hope_i) + \varepsilon_{it} \quad (2)$$

where, for each household i (i=1,2,…,N) at time t (t=1,2,…,T): Y is the outcome of interest such as probability of cultivating sorghum/finger millet and farmer awareness or adoption of improved varieties; x is a vector of control variables, including farmer and household characteristics such as age, sex, farming experience and education level of the farmer, household size, size of land and value of livestock owned; □ is a vector of unknown parameters to be estimated; Round2 is a year (survey round) dummy equal to 0 for observations in the first round (baseline) and 1 for those in the second round (early-adoption), which controls for time trends that are common in both treatment and control areas; Hope is a dummy variable equal to 1 if a household is located in the HOPE project area and 0 otherwise, and it controls for differences in treatment and control areas that were not due to the HOPE project; ε is the error term; and □ are unknown parameters to be estimated. The parameter of interest is γ_3, which represents the difference in the outcome variable between the treatment and control areas in the early adoption survey. It measures the impact of HOPE activities on outcome variables, conditional on control variables. The equation was estimated using random and fixed effects models, which also control for unobserved household-level variables that may influence changes in outcomes (Baltagi, 2008).

For productivity analysis, we followed Battese and Coelli (1995), and apply the panel data stochastic frontier framework:

$$Y_{it} = \exp(\boldsymbol{x_{it}\beta} + V_{it} - U_{it}) \qquad (3)$$

where, for each household i (i=1,2,…,N) at time t (t=1,2,…,T): Y is the sorghum output of household; x is a vector of productive inputs and other variables that may influence output; β is a vector of parameters to be estimated; V_{it} are random errors, assumed to be iid $N(0, \sigma_v^2)$ and independently distributed of U_{it}; U_{it} are random non-negative truncations of the normal distribution with mean, $z_{it}\delta$ and variance, σ_u^2, and they represent technical inefficiency – the percentage deviation of an individual household's observed output from the potential output given by the production frontier.

The technical inefficiency component in equation 3 can thus be expressed as

$$U_{it} = z_{it}\delta + W_{it} \qquad (4)$$

where z is a vector of variables associated with technical inefficiency (farmer, farm and environmental characteristics, but may include some productive input variables as well); δ is a vector of parameters to be estimated; and W_{it} are random factors associated with technical inefficiency.

Equations 3 and 4 are simultaneously estimated by maximum likelihood methods, following which parameters $\sigma \equiv \sqrt{\sigma_u^2 + \sigma_v^2}$ and $\lambda \equiv \sigma_u/\sigma_v$ are generated. The parameter λ measures the ratio of variability of the technical inefficiency to that of stochastic error, also known as the "signal-to-noise ratio". A small value of λ implies that technical inefficiency is not a stochastic component of equation 3. Similarly, if δ are jointly insignificant, then inefficiency effects are not associated with the z_{it}. If these two conditions hold, it means that equation 4 can be omitted, and an average production function, instead of equation 3, estimated using ordinary least squares (OLS).

The empirical stochastic frontier model used was

$$\begin{aligned} lnProduction_{it} = \beta_0 &+ \beta_1 lnLand_{it} + \beta_2 lnLabor_{it} + \beta_3 lnSeed_{it} + \beta_4 Improved_{it} \\ &+\beta_5 Intercrop_{it} + \beta_6 lnManure_{it} + \beta_7 Mechprep_{it} \\ &+\beta_8 Birdscar_{it} + \beta_9 Kondoa_i + \beta_{10} Round2_t + \beta_{11} Hope_i \\ &+\beta_{12}(Round2_t * Hope_{i)} + V_{it} - U_{it}) \end{aligned} \qquad (5)$$

where, ln is the natural logarithm; Production is grain output (tons); Land is plot size (Ha); Seed is quantity of seed used (kg); Labour is the quantity of labour used (person days); Improved is a dummy variable = 1 if variety used is improved and zero otherwise; Intercrop is a dummy variable = 1 if plot was intercropped and zero otherwise; Manure represents the quantity of manure used (Kg)4; Mechprep is a dummy variable equal to 1 if land preparation was mechanized (tractor or ox plough used) and zero otherwise; Birdscar is a dummy variable = 1 if bird scaring was done to reduce grain damage and zero otherwise; Kondoa is a dummy variable = 1 if household is located in Kondoa District and zero otherwise; and Round2 is a dummy variable = 1 if observation is in second survey round and zero otherwise (baseline).

The technical inefficiency model was specified as

$$\begin{aligned} U_{it} = \delta_0 &+ \delta_1 Female_{it} + \delta_2 Experience_{it} + \delta_3 Education_{it} + \delta_4 Hhsize_{it} \\ &+ \delta_5 Fem1564_{it} + \delta_6 Mal1564_{it} + \delta_7 Radio_{it} + \delta_8 Mobile_{it} \\ &+ \delta_9 Livestock_{it} + \delta_{10} Kondoa_{it} + \delta_{11} Round2t_t + \delta_{12} Hope_i \\ &+ \delta_{13}(Round2_t * Hope_i) + W_{it} \end{aligned} \quad (6)$$

where, Female is a dummy for sex of respondent (1 if female, 0 otherwise); Experience is number of years since respondent started sorghum farming; Education is dummy variable = 1 if respondent has over 4 years of formal education and 0 otherwise; Hhsize is number of members in the household; Fem1564 is the number of female household members aged 15-64 years; Mal1564 is the number of male household members aged 15-64 years; Radio is dummy variable = 1 if household owns at least one radio and zero otherwise; Mobile is dummy variable = 1 if household owns at least one mobile phone and zero otherwise; and Livestock is the value of livestock owned in millions of Tanzanian Shillings. Other variables are as defined above.

Equations 4 and 5 were estimated using the Battese and Coelli (1995) model and the true random effects model (Greene, 2005). A pooled model was also estimated for comparison. To estimate treatment effects in both equations, we first use the dummy variable Round2 to control for time trend – changes that would have occurred between baseline and early-adoption surveys in both treatment and control areas, even without the project. We then use the Hope project dummy variable to control differences between treatment and control areas that are independent of Hope. Finally, an interaction term between the time trend and Hope project dummy $(\mathrm{Round2_t} * \mathrm{Hope_i})$ is used to estimate the treatment effect, i.e., the effect of being in the project area in the second round, on productivity and technical efficiency (project impacts). More on this approach can be found in Wooldridge (2009). Plot level data were used in the stochastic frontier analysis. This was because many farmers grew sorghum in more than one plot and it was easier and more accurate to recall production data by plot. Since labour data was more challenging for farmers to estimate, each farmer was asked to provide labour data by production activity for only one sorghum plot, which was then used for productivity analysis. The variables used are described in Table 6.

[4] Zero use of manure was accounted for by letting *lnManure* = ln[Max $(\mathrm{Manure_{it}}$, 1-$\mathrm{M_{it}})$], where M_{it} is a dummy variable equal to 1 if manure was used and 0 otherwise (Battese and Coelli,1995).

Table 6: Descriptive statistics of variables used in stochastic frontier analysis

Variable	Description	Baseline (N=203)		Early-adoption (N=193)	
		Treatment (n=91)	Control (n=112)	Treatment (n=79)	Control (n=114)
Output					
Production	Quantity of grain harvested (tons)	0.34 (0.76)	0.37 (0.36)	0.34 (0.40)	0.49 (0.65)*
Yield	Grain yield (tons ha^{-1})	0.49 (0.44)	0.59 (0.58)*	0.62 (0.62)	0.69 (0.81)*
Inputs					
Land	Size of plot (ha)	0.71 (0.86)	0.78 (1.00)	0.67 (0.92)	0.82 (0.69)
Labour	Total labour (days)	81.1 (58.3)	106 (110.7)**	91.9 (65.2)	129.6 (117.4)***
Labourha	Labour use rate (days ha^{-1})	162 (150.8)	197 (197.0)*	227 (257.6)	229 (352.7)
Seed	Total seed used (kg)	6.37 (6.84)	6.94 (8.03)	7.10 (10.01)	8.50 (9.81)
Seedha	Seed rate (kg ha^{-1})	12.5 (14.98)	12.5 (16.37)	12.6 (15.06)	11.6 (9.53)
Improved	Improved seed was used (0=No, 1=Yes)	0.22 (0.42)	0.20 (0.40)	0.32 (0.47)	0.23 (0.42)*
Usemanu	Used manure in plot (0=No, 1=Yes)	0.08 (0.27)	0.06 (0.24)	0.22 (0.41)	0.25 (0.43)
Manure	Total manure used (kg)	3.92 (31.7)	270.3 (1996)	1.15 (2.78)	1.89 (5.14)
Manuha	Manure use rate (kg ha^{-1})	5.94 (40.35)	465.2 (3359)*	2.58 (6.81)	1.88 (4.13)
Intercrop	Plot was intercropped (0=No, 1=Yes)	0.36 (0.48)	0.20 (0.40)***	0.08 (0.27)	0.11 (0.32)
Mechpreps	Mechanical (tractor/oxen) land preparation (0=No, 1=Yes)	0.34 (0.48)	0.37 (0.48)	0.39 (0.49)	0.29 (0.46)
Birdscar	Bird scaring was done (0= No, 1=Yes)	0.35 (0.48)	0.41 (0.49)	0.46 (0.50)	0.30 (0.46)**
Kondoa	Plot is in Kondoa District (0=No, 1=Yes)	0.46 (0.50)	0.60 (0.49)**	0.39 (0.49)	0.49 (0.50)*
Technical inefficiency covariates					
Female	Respondent is female (0=No, 1=Yes)	0.15 (0.36)	0.15 (0.36)	0.24 (0.43)	0.25 (0.43)
Farmexpr	No. of years since respondent started farming	22.3 (10.9)	23.1 (12.7)	26.6 (11.2)	25.0 (11.0)
Education	Education of respondent (0= less than 4 years, 1=4 years or more.	0.80 (0.40)	0.81 (0.39)	0.84 (0.37)	0.84 (0.37)
Hhsize	Number of household members.	6.90 (2.29)	6.17 (2.21)***	6.82 (2.37)	6.54 (2.44)
Fem1564	No. of female household members aged 15-64 years.	1.66 (1.17)	1.58 (1.00)	1.47 (0.93)	1.57 (0.94)
Mal1564	No. of male household members aged 15-64 years.	1.69 (1.22)	1.71 (1.07)	1.87 (1.09)	1.78 (1.15)
Radio	Household owns a radio (0=No, 1=Yes).	0.74 (0.44)	0.77 (0.42)	0.70 (0.46)	0.81 (0.40)**
Mobile	Household owns a mobile phone (0=No, 1=Yes).	0.51 (0.50)	0.41 (0.49)*	0.72 (0.45)	0.69 (0.46)
Livestock	Value of livestock owned (TSh million).	0.64 (1.16)	0.74 (1.25)	0.53 (0.67)	0.59 (0.67)

Note: Figures are mean values, with standard deviations in brackets. *, **, *** differences between treatment and control groups are significant at 10%, 5% and1% respectively following a t-test.

4. Results

4.1 Awareness and adoption

Results are presented in Table 7 while results stratified by treatment, diffusion and control areas and district are shown in Table A2. The analysis is restricted to sorghum since the sample size for awareness and adoption of improved varieties of finger millet in the early adoption survey was too small for statistical analysis.

For the entire sample, the share of farmers that were aware of improved varieties increased by 31%, from 49 % in 2009 to 80 % in 2012. Awareness of improved varieties among the treatment group rose by 35 % (from 45% in 2009 to 80 % in 2012), whereas awareness among the control group rose by 21%, from 54 % to 80 %. Thus, the unconditional impact of the HOPE project was to raise awareness by 9.5 %. Similarly, for the entire sample, the intensity of awareness (the number of improved varieties a farmer could name) rose from an average of 0.84 in 2009 to 1.67 in 2012. Among the treatment group, the average number of improved varieties a farmer could name rose by 1.01, from 0.8 in 2009 to 1.81 in 2012. By contrast, in the control group, the intensity of awareness rose from 1.0 to 1.6. Thus, the unconditional impact of the HOPE project was to raise the intensity of awareness by 0.34 improved varieties.

Table 7: Difference-in-differences estimates for awareness and adoption of improved sorghum varieties

	Incidence (%)			Intensity (%)		
	Baseline	Early Adoption	*Difference*	Baseline	Early Adoption	*Difference*
Awareness						
Total	49.2	80.3	*31.1****	0.84	1.67	*0.83***
Treatment	45.1	79.9	*34.8****	0.80	1.81	*1.01****
Control	54.4	79.7	*25.3****	0.88	1.55	*0.67****
Difference	*-9.3*	*0.2*	***9.5***	*-0.08*	*0.26***	***0.34***
Adoption						
Total	26.9	44.5	*17.6****	19.4		
Treatment	25.0	51.6	*26.6**	21.7	34.9	*13.2***
Control	27.6	41.0	*13.4**	19.0	25,5	*6.5**
Difference	*-2.6**	*10.6**	***13.2***	*2.7*	*9.4***	***6.7***

Note: *, **, *** differences between treatment and control groups are significant at 10%, 5% and 1% respectively, following t-tests. **Bold** figures are the mean difference-in-differences, which represent project impacts (ATT).

For the entire sample, the share of farmers growing improved varieties increased by 18 %, from 27 % in 2009 to 45 % in 2012. Among the treatment group, the share of farmers growing improved varieties rose by 32 %, from 21% at baseline to 53 % in the early-adoption survey. By contrast, in the control group, the increase in the share of farmers growing improved varieties was only 6 %. Thus, the unconditional impact of the HOPE project was to raise adoption by 13.2%. Similarly, for the entire sample, the intensity of adoption (the share of the crop planted to improved varieties) increased by 10%, from 19 % in 2009 to 29 % in 2012. Among the treatment group, the intensity of adoption rose by 17 %, from 18 % in 2009 to 35 % in 2012. By contrast, in the control group, the intensity of adoption did not change.

Thus, the unconditional impact of the HOPE project was to increase the intensity of adoption by 6.7%.

To check the robustness of these impacts we estimated Equation 2 (Table 8). To analyze the probability of exposure and adoption, logit models were used, while for the analysis of intensities of exposure and adoption, Poisson and linear regressions were used, respectively. For comparative purposes, we estimated both fixed and random effects models. However, the explanatory power of the fixed-effects models for exposure was very poor, and the results were discarded. The variable of interest is R2*Hope, which captures the ATT or impact of HOPE on exposure and adoption.

Model (1) shows that when exposure is defined by a binary variable, HOPE increased the probability of knowing at least one variety by about 9 %, which was statistically insignificant. However, when exposure is defined in terms of intensity, a weakly significant positive impact of 0.32 varieties was found (Model 2), which is comparable to the unconditional impact of 0.34. Hence, the unconditional difference-in-difference estimates did not differ significantly from those in the regression analysis. Nevertheless, adding the control variables is more informative. Farmers in Kondoa District and those owning larger parcels of land were more exposed than their counterparts in Singida Rural and those owning smaller land parcels, respectively. Exposure increased with age, but this impact diminished as farmers became older.

The results for adoption show some differences between the fixed- and random-effects models, with the former exhibiting positive impacts, whether probability of adoption or area under improved varieties is used to measure rate of adoption. The fixed effects model (5) shows an impact of 28% which is more than double the effect in the unconditional differencing results. Model (6) shows that the proportion of sorghum planted to improved varieties increased by 13 % in the treatment villages, which was almost twice the unconditional impact of 7 %. Adoption rates were higher in Kondoa than in Singida Rural, and increased with the size of land owned by a household. The rates decreased with sorghum farming experience, but at a decreasing rate.

These findings imply that HOPE raised awareness and adoption of improved varieties among farmers, regardless of how the two variables were measured. However, statistically robust conclusions on hypotheses 1 and 2 depend on model specifications. If exposure is modeled as a binary variable, we cannot reject the null hypothesis that HOPE had no impact on farmer awareness of improved varieties. By contrast, if exposure is measured in terms of intensity, we reject this hypothesis at the 90% level of confidence and conclude that HOPE significantly increased awareness of improved varieties. On adoption, results of random effects models imply that we cannot reject the null hypothesis that HOPE had no impact on the adoption of improved varieties, regardless of how adoption is measured. On the other hand, if fixed effects models are used, we can reject the null hypothesis and conclude that HOPE increased the adoption of improved sorghum varieties.

Table 8: Regression results for impact of HOPE on awareness and adoption

Variable	Probability of awareness (1)	Intensity of awareness (2)	Probability of adoption		Intensity of adoption	
			Fixed effects (3)	Random effects (4)	Fixed effects (5)	Random effects (6)
Round2	0.234***	0.693***	0.223***	0.182***	10.002*	8.204*
	(0.049)	(0.132)	(0.081)	(0.062)	(5.254)	(4.458)
Hope	-0.084*	-0.128		0.008		4.237
	(0.044)	(0.162)		(0.070)		(4.724)
Round2*Hope	0.090	0.321*	0.280**	0.116	12.868*	8.243
	(0.069)	(0.189)	(0.114)	(0.090)	(6.647)	(6.530)
Kondoa	0.188***	0.470***		0.117**		12.311***
	(0.036)	(0.104)		(0.052)		(4.169)
Female	-0.073	-0.365***	-0.226*	0.015	-15.776	-2.189
	(0.044)	(0.134)	(0.116)	(0.061)	(10.388)	(5.359)
Age	0.031***	0.072***				
	(0.010)	(0.028)				
Agesq	-0.029***	-0.063**				
	(0.010)	(0.028)				
Sorgexpr			-0.039***	-0.017***	-2.074***	-1.496***
			(0.011)	(0.006)	(0.749)	(0.517)
Sorgexpr2			0.062***	0.027**	3.351**	2.279**
			(0.023)	(0.012)	(1.511)	(0.958)
Ownland	0.003*	0.005***	0.008*	0.005***	0.285*	0.241**
	(0.002)	(0.001)	(0.004)	(0.002)	(0.149)	(0.094)
N	644	643	156	451	451	451

Note: *Agesq* = square of respondent's age divided by 100; *Sorgexpr2*= square of respondent's sorghum farming experience divided by 100. Other variables controlled for are sorghum area, household size, livestock value, and ownership of radio, mobile phone and ox-plough. All households in the matched sample are used in the exposure models, while in the adoption models, only sorghum growers were used, since non-growers cannot be expected to adopt. Figures are marginal effects; with standard errors in brackets. *, **, *** effects are significant at 10%, 5% and 1% respectively.

4.2 Area, yields, and output

4.2.1 Area planted

Table 9 shows changes in the share of farmers growing sorghum and finger millet and the area planted to these crops, together with pearl millet, maize and sunflower, an emerging cash crop. Results stratified by treatment, diffusion and control villages can be found in Table A3.

Among the entire sample, the share of farmers growing sorghum remained constant at 70 % between the two survey rounds. However, the share of farmers growing finger millet fell by 38%, from 71 % in 2009 to 33 % in 2012. By contrast, the share of farmers growing maize and sunflower rose by 21% and 23 %, respectively. Overall, the area planted to sorghum did not change significantly but the area planted to finger millet fell by 63 %, from 0.67 to 0.25 ha. By contrast the area planted to maize did not change, while the area planted to sunflower rose by 86 %, from 0.35 to 0.65 ha.

HOPE did not increase the share of farmers growing sorghum or the average area planted to sorghum in the treatment group. The same was true for finger millet. In fact, the share of farmers growing finger millet in the treatment group dropped by 37%, from 81 % in 2009 to

44% in 2012. The area planted to finger millet among the control group also fell. The control group experienced the same rate of decline in the share of finger millet growers and area planted. Among the treatment group, there was a 24 % increase in the share of farmers growing maize, and a 26 % increase in the share growing sunflower. These increases were significantly higher than those in the control group.

Table 9: Difference-in-differences estimates for cropping patterns

	Growers (%)			Area (ha)		
	Baseline	Early-Adoption	*Difference*	Baseline	Early-Adoption	*Difference*
Sorghum						
Total	70.3	71.4	*1.1*	0.61	0.72	*0.11**
Treatment	63.4	53.7	*-6.7*	0.49	0.50	*0.02*
Control	77.8	84.7	*6.9***	0.86	0.93	*0.07*
Difference	*14.4 ****	*31.0****	***15.6***	*0.37***	*0.43****	***0.06***
Finger millet						
Total	70.8	32.9	*-37.9****	0.67	0.25	*-0.42****
Treatment	81.1	43.9	*-37.2*	0.87	0.36	*-0.51*
Control	58.8	19.9	*-38.9*	0.47	0.13	*-0.34*
Difference	*22.3****	*24.0****	***1.7***	*0.40*	*0.23*	***0.17***
Pearl millet						
Total	*48.9*	*36.7*	*-12.2****	*0.38*	*0.25*	*-0.13****
Treatment	40.2	37.8	*-2.4*	0.32	0.25	*-0.07*
Control	60.3	33.4	*-26.9***	0.53	0.27	*-0.26***
Difference	*20.1****	*4.4*	***15.7***	*0.21***	*0.02*	***0.19***
Maize						
Total	67.5	88.4	*20.9***	0.85	0.89	*0.04*
Treatment	63.4	87.2	*23.8****	0.80	0.84	*0.04*
Control	78.7	88.3	*9.6***	0.99	0.95	*-0.04*
Difference	*15.3****	*1.1*	***14.2***	*0.19*	*0.11*	***0.08***
Sunflower						
Total	34.2	56.7	*22.5****	0.35	0.65	*0.30****
Treatment	33.5	59.1	*25.6****	0.29	0.54	*0.25****
Control	40.5	54.4	*13.9****	0.42	0.75	*0.33***
Difference	*7.0**	*4.7*	***2.3***	*0.46*	*0.21**	***0.25***

Note: Figures are means. *, **, *** differences between treatment and control groups or survey rounds are significant at 10%, 5% and 1% respectively.

Next we discuss the results of panel data regression analysis for the matched sample (Table 10, equation 2). To estimate the impact of HOPE on the probability of growing a certain crop, we estimated random effects probit models, while random effects linear models were used to estimate impact on crop area allocations5. Table 10 shows the results of this analysis, with models (1) - (5) showing results for the probit models (marginal effects), and models (6) - (10) the linear models. We control for several variables but discuss results for only the most interesting.

The HOPE project significantly decreased the probability of cultivating sorghum by 16.8 %, which is comparable to the negative treatment effect (-13.6 %) on the proportion of sorghum

[5] Fixed effects models were also estimated but they had very poor goodness-of-fit so the results were discarded.

growers implied in Table 9. The impact on pearl millet (-29.3%) was also comparable to the unconditional one of -24.5 %. The impact of HOPE on the probability of cultivating finger millet, maize and sunflower were insignificant. Area planted showed weakly significant impacts for sorghum (-0.26 ha) and pearl millet (0.14 ha), strong significant impacts for sunflower (0.16 ha), and insignificant effects for finger millet and maize. Based on these findings, we fail to reject Hypothesis 1 for finger millet and conclude that HOPE had no impact on the cultivation of finger millet. However, the hypothesis is rejected for sorghum, but the conclusion that HOPE had a negative impact on the area planted to sorghum is contrary to expectation.

Table 10: Regression results for drivers of crop cultivation and area planted

Variable	Probability of cultivating crop					Crop area				
	Sorghum (1)	Finger millet (2)	Pearl millet (3)	Maize (4)	Sunflo-wer (5)	Sorghum (6)	Finger millet (7)	Pearl millet (8)	Maize (9)	Sunflo-wer (10)
Round2	0.121**	-0.385***	-0.329***	0.139***	0.350**	0.317***	-0.247**	-0.216***	0.014	0.172***
	(0.054)	(0.045)	(0.058)	(0.040)	(0.152)	(0.100)	(0.125)	(0.058)	(0.093)	(0.057)
Hope	-0.139**	0.244***	-0.255***	-0.081**	-0.032	-0.099	0.512***	-0.130**	0.003	-0.087
	(0.055)	(0.052)	(0.068)	(0.037)	(0.113)	(0.108)	(0.123)	(0.065)	(0.105)	(0.065)
R2*Hope	-0.168**	-0.007	0.293***	0.056	-0.105	-0.256*	-0.237	0.144*	-0.080	0.163**
	(0.068)	(0.067)	(0.081)	(0.056)	(0.172)	(0.132)	(0.168)	(0.077)	(0.124)	(0.079)
Kondoa	-0.073	-0.318***	-0.101	0.194***	0.023	-0.245***	-0.396***	0.038	0.568***	0.093*
	(0.049)	(0.042)	(0.062)	(0.037)	(0.147)	(0.093)	(0.099)	(0.057)	(0.092)	(0.053)
Ownland	0.003**	0.003*	-0.003	0.008**	0.017**	0.027***	0.021***	0.004***	0.026***	0.001
	(0.001)	(0.001)	(0.002)	(0.004)	(0.007)	(0.002)	(0.003)	(0.001)	(0.002)	(0.001)
Plough	-0.035	0.087*	-0.037	0.096**	0.255	0.049	0.203*	0.024	0.436***	0.077
	(0.052)	(0.053)	(0.067)	(0.049)	(0.190)	(0.105)	(0.119)	(0.063)	(0.101)	(0.060)
Male1564	0.038*	0.044**	-0.003	-0.023	0.056	0.081*	0.272***	0.009	0.050	-0.004
	(0.021)	(0.022)	(0.028)	(0.018)	(0.058)	(0.041)	(0.045)	(0.025)	(0.040)	(0.025)
N	641	641	641	641	641	641	641	641	641	641

Note: Other variables controlled for are farming experience, sex and education of household head; household size, number of female members aged 15-64 years, ownership of radio and mobile phone, and livestock wealth. *, **, *** effects are significant at 10%, 5% and 1% respectively.

Table 10 also shows that households in Kondoa were less likely to grow finger millet, and planted a bigger area to millets than those in Singida Rural. In addition, they were more likely to cultivate maize, and planted a bigger area to maize and sunflower than their counterparts in Singida Rural. The probability of cultivating all crops except finger millet, and area allocated to all crops except sunflower, increased with the amount of land the household owned. Farmers owning ox-ploughs were more likely to grow finger millet and maize, and allocate a larger area to the two crops, perhaps due to the higher labour requirements for land preparation and sowing. Male labour seems to be an important factor in cultivation of sorghum and finger millet, as the number of male household members aged 15-64 years positively influenced the probability of cultivating as well as the area planted to these crops.

4.2.2 Yields and production

Table 11 compares the average production of sorghum grain per household and yields per ha for the treatment and control groups. Results disaggregated by treatment, diffusion and control villages can be found in Table A4. Since improved varieties of finger millet were not available in 2009, we compared yield changes only for sorghum.

For the entire sample, sorghum production per household showed a significant increase from 0.395 to 0.563 tons. Among the treatment group, however, there was no increase in sorghum production, while production among control households rose by 51 % from 0.430 to 0.644 tons. Thus, the HOPE project had no significant impact on sorghum production at the household level.

Table 11: Difference-in-differences estimates for sorghum production and yields

	Production (tons/household)			Yield (tons ha^{-1})		
	Baseline	Early Adoption	*Difference*	Baseline	Early Adoption	*Difference*
All sorghum						
Total	0.395	0.563	*0.168****	0.537	0.648	*0.111***
Treatment	0.353	0.445	*0.092*	0.487	0.596	*0.109**
Control	0.430	0.644	*0.214****	0.578	0.684	*0.106**
Difference	*-0.077*	*-0.199***	***-0.122***	*-0.091**	*-0.088*	***0.003***
Improved varieties						
Total	0.328	0.295	*-0.033*	0.671	0.603	*-0.068*
Treatment	0.259	0.285	*0.026*	0.595	0.566	*-0.029*
Control	0.380	0.304	*-0.076*	0.730	0.634	*-0.096*
Difference	*-0.121*	*-0.019*	***0.102***	*-0.135*	*-0.068*	***0.067***
Local varieties						
Total	*0.308*	*0.429*	*0.121***	*0.496*	*0.674*	*0.178****
Treatment	0.288	0.298	*0.010*	0.457	0.611	*0.154***
Control	0.325	0.520	*0.195****	0.527	0.713	*0.186***
Difference	*-0.037*	*-0.222****	***-0.185***	*-0.070*	*-0.102*	***-0.032***

Note: *, **, *** differences between treatment and control groups or survey rounds are significant at 10%, 5% and 1% respectively, following t-tests. **Bold** figures are the mean difference-in-differences, which represent project impacts (ATT).

For the entire sample, the mean yield of sorghum rose by 21 %, from 0.52 to 0.63 tons ha-1. Among the treatment group, average yields rose by 25 %, from 0.50 to 0.62 tons ha-1, while in the control group they rose by 17 %, from 0.59 to 0.70 tons ha-1. Thus, the HOPE project had a positive impact on sorghum yield, although this was small (0.024 tons ha-1). In both survey rounds, the absolute yield of sorghum was higher in the control group.

The HOPE project had no positive impact on the average yields of improved sorghum varieties. However, average yields for local varieties increased between the two survey rounds, for both the treatment and control groups. Hence, the increase in the average yield of sorghum between the two survey rounds reflected not only higher adoption of improved varieties but higher yields from local varieties.

Table 12 compares yields for improved and local varieties of sorghum in both survey rounds. Average yields were significantly higher (26 %) for improved varieties at baseline, but were not significantly different in the early adoption survey. In both survey rounds, the average yield of improved sorghum varieties was below 0.7 tons ha-1.

Table 12: Difference-in-differences estimates for sorghum yields (tons ha^{-1})

Survey round	Improved varieties	Local varieties	Difference
Baseline			
All sample	0.671	0.496	0.175***
- Treatment	0.595	0.457	0.138*
- Control	0.730	0.526	0.204**
Difference	*-0.135*	*-0.070*	***-0.065***
Early adoption			
All sample	0.602	0.674	-0.072
- Treatment	0.566	0.611	-0.045
- Control	0.634	0.713	-0.079
Difference	*-0.068*	*-0.102*	***0.034***

Table 13 shows the use of improved crop management practices for sorghum and finger millet. The rate of manure applied to sorghum fell by 43 % from 7.5 tons ha-1 in 2009 to 4.27 tons ha-1 in 2012. However, the share of farmers applying manure to sorghum rose by 16.4 %, from just 9.1% in 2009 to 25.6% in 2012. However, increase was primarily in the control group. There was no increase in the share of farmers applying seed treatment.6 . No farmers used inorganic fertilizer, which is not shown. For finger millet, the rate of manuring did not change significantly between the two surveys, while the share of farmers applying manure rose by 8%. The HOPE project did increase the share of farmers applying manure to finger millet and using seed treatment, but only by 2%. Thus, the HOPE project had no positive impact on improved crop management for sorghum and only limited impact for finger millet.

To obtain more robust results, we controlled for some variables by estimating stochastic frontier models in Equations 4 and 5 (Table). Model (1) shows results for the baseline observations, while results in model (2) are for the pooled sample. Results for the panel data methods are shown in models (3) (Battese and Coelli 1995 model, BC95) and (4) (True random effects, TRE). We find that the coefficients of all key inputs in the production frontier have the expected positive signs, except for labour in model (3), implying that grain output increased with land size, and amounts of seed and manure used.

Controlling for other factors, output was higher for improved than traditional varieties, but the level of significance was low for the pooled and TRE models. The negative and significant coefficients on the bird-scaring dummy is surprising, but may indicate that farmers who had severe problems with bird damage obtained lower yields than others.

[6] Seed treatment methods used were ash and fungicide. However, it is not very clear whether farmers purchased the fungicides or they were referring to seed treatment that comes with certified seeds.

Table 13: Difference-in-differences estimates for crop management of sorghum and finger millet

	Sorghum			Finger millet		
	Baseline	Early Adoption	*Difference*	Baseline	Early Adoption	*Difference*
Manuring (tons ha^{-1})						
Total sample	7.50	4.27	*-3.23***	5.79	6.14	0.35
Treatment	7.51	4.74	*-2.77*	5.33	5.67	0.34
Control	7.49	4.03	*-3.46***	6.33	7.22	0.89
Difference	*0.02*	*0.71*	***0.69***	*-1.00*	*-1.55*	***-0.55***
Manuring (% farmers)						
Total sample	9.1	25.6	16.4***	6.5	14.5	8.0***
Treatment	11.5	22.6	11.0**	8.2	16.7	8.5**
Control	7.1	27.6	20.5***	4.2	10.5	6.3*
Difference	*4.4*	*-5.0*	***-9.5***	*4.0*	*6.2*	***2.2***
Seed treatment (% farmers)						
Total	3.9	7.5	3.6**	0.9	2.7	1.8*
Treatment	6.5	2.9	*-3.6*	0.0	2.7	2.7**
Control	8.1	4.8	*-3.4*	2.2	2.7	0.5
Difference	*-1.6*	*-1.9*	***0.2***	*-2.2***	*0.0*	***2.2***

Note: [a] Manure application rate is calculated only for farmers who used manure. *, **, *** difference between treatment and control groups or survey rounds is significant at 10%, 5% and 1% respectively, following t-tests. **Bold** figures are the mean difference-in-differences, which represent project impacts (ATT).

The baseline model shows that sorghum output was about 14% lower for treatment than control households. This difference was insignificant, but comparable to the negative baseline yield difference of 19% implied in Table 11. Moving to the pooled and panel data methods, the variable of interest is R2*Hope, the interaction term between HOPE and early-adoption survey dummies. We find positive but insignificant coefficients indicating an average treatment effect ranging from 24.2% to 28.2%. As shown in Table 11, yield differences for treated households between the two surveys differed from those of the control households by about 2.8%. The huge difference between the effects estimated by R2*Hope and the unconditional difference-in-differences estimates are perhaps due to the fact that the former estimates are based on plot data, while the latter are based on aggregate household production. These results imply that HOPE did not have significant impact on sorghum yields. However, improved varieties produced higher yields than local varieties.

Table 14: Regression results for determinants of sorghum output

a) Production frontier model

Variable	Base (1)	Pooled (2)	BC95 (3)	TRE (4)
Lnland	0.702***	0.555***	0.735***	0.554***
	(0.118)	(0.092)	(0.114)	(0.092)
Lnlabour	-0.018	0.030	-0.095	0.028
	(0.071)	(0.066)	(0.067)	(0.066)
Lnseed	0.171**	0.173***	0.175***	0.173***
	(0.073)	(0.059)	(0.064)	(0.059)
Improved	0.498***	0.212*	0.362**	0.210*
	(0.158)	(0.125)	(0.155)	(0.126)
Intercrp	-0.100	-0.197*	-0.150	-0.197*
	(0.130)	(0.113)	(0.133)	(0.113)
Lnmanu	0.079***	0.089***	0.089***	0.088***
	(0.023)	(0.020)	(0.025)	(0.020)
Mechpreps	-0.194	0.136	-0.111	0.137
	(0.120)	(0.107)	(0.120)	(0.107)
Birdscar	-0.388***	-0.204**	-0.248**	-0.202**
	(0.115)	(0.096)	(0.126)	(0.096)
Kondoa	0.179	0.183	0.035	0.184
	(0.149)	(0.121)	(0.130)	(0.122)
Round2		0.150	1.741***	0.155
		(0.147)	(0.237)	(0.147)
Hope	-0.141	-0.094	-0.180	-0.097
	(0.163)	(0.158)	(0.164)	(0.158)
R2*Hope		0.251	0.282	0.242
		(0.251)	(0.372)	(0.253)
Constant	-0.542	-0.937***	-0.590*	-0.936***
	(0.334)	(0.325)	(0.323)	(0.325)
Log Likelihood	-229.3	-503.2	-359.4	-503.0
Chi2	140.5	176.9	193.9	175.0
Prob > Chi2	0.000	0.000	0.000	0.000
σ_u	0.547	0.704	2.447	0.701
σ_v	0.567	0.606	0.607	0.592
Σ	0.788	0.929	2.521	0.918
λ	0.965	1.162	4.031	1.184

b) Technical Inefficiency model

Variable	Base (1)	Pooled (2)	BC95 (3)	TRE (4)
Female	-0.111	0.029	0.143	0.038
	(0.482)	(0.319)	(0.341)	(0.320)
Farmexpr	0.008	0.021*	0.026	0.021*
	(0.020)	(0.012)	(0.017)	(0.012)
Education	0.122	-0.242	0.493	-0.237
	(0.661)	(0.350)	(0.503)	(0.353)
Hhsize	0.144	0.046	-0.042	0.044
	(0.122)	(0.075)	(0.093)	(0.076)
Fem1564	-0.221	0.028	0.031	0.026
	(0.181)	(0.148)	(0.141)	(0.149)
Mal1564	-0.010	0.046	0.102	0.048
	(0.220)	(0.116)	(0.132)	(0.116)
Radio	-0.339	-0.080	-0.969	-0.075
	(0.455)	(0.313)	(0.618)	(0.314)
Plots	-0.182	0.424**	0.516***	0.426**
	(0.351)	(0.191)	(0.194)	(0.192)
Ownland	0.007	-0.005	0.015*	-0.005
	(0.007)	(0.007)	(0.009)	(0.007)
Livestock	-0.516***	-0.436***	-0.692***	-0.438***
	(0.185)	(0.143)	(0.215)	(0.144)
Kondoa	1.240**	1.234***	0.786**	1.247***
	(0.576)	(0.382)	(0.399)	(0.387)
Round2		0.452	7.497***	0.461
		(0.488)	(1.207)	(0.491)
Hope	0.175	0.238	0.303	0.232
	(0.527)	(0.559)	(2.815)	(0.562)
R2*Hope		0.488	-0.610	0.475
		(0.721)	(2.982)	(0.727)
Constant	-2.199*	-2.871***	-5.637***	-2.891***
	(1.246)	(0.926)	(1.167)	(0.938)
N	200	393	393	393
Test:				
δ_1=δ_2=,…,=δ_k,=0	20.92	45.92	172.2	45.21
	(0.052)	(0.000)	(0.000)	(0.000)
Mean TE	0.629	0.571	0.560	0.574
	(0190)	(0.216)	(0.373)	(0.220)

Note: Figures in brackets are robust standard errors (standard deviation for mean TE, p-value for the test δ_1=δ_2=,…,=δ_k =0). *, **, *** coefficients are significant at 10%, 5% and 1% respectively.

4.3 Commercial seed channels

Table 15 shows farmers' sources of seed in both survey rounds. Detailed information on seed sources stratified by treatment, diffusion and control villages can be found in Table A8. Among the entire sample, only about 2 % of farmers growing improved sorghum obtained seed through commercial channels. This did not change between the two survey rounds. At baseline, the main channel through which farmers obtained improved seed was through extension officers (44%). By the time of the early adoption survey, however, the most popular method of obtaining improved seed was ‘own store’, or saving seed from the previous harvest.

Table 15: Sources of improved sorghum seed (% farmers using each channel)

Commercial channels	Baseline	Early Adoption	*Difference*
Total	0.016	0.019	*-0.003*
Treatment	0.038	0.042	*0.004*
Control	0.000	0.000	*0.000*
Difference	*0.038*	*0.042**	***0.004***
Farmer-to-farmer			
Total	0.132	0.109	*0.023*
Treatment	0.077	0.146	*0.069*
Control	0.147	0.091	*-0.056*
Difference	*-0.070*	*0.055*	***0.125***
Extension officer			
Total	0.441	0.273	*0.168*
Treatment	0.385	0.188	*-0.197***
Control	0.471	0.345	*-0.125*
Difference	*-0.086*	*-0.157*	***-0.072***
Own store			
Total	*0.294*	*0.491*	*-0.197*
Treatment	*0.423*	*0.583*	*0.160**
Control	*0.206*	*0.436*	*0.230***
Difference	*0.217***	*0.147**	***-0.07***

Note: *, **, *** differences between treatment and control groups or survey rounds are significant at 10%, 5% and 1% respectively, following t-tests. **Bold** figures are the difference-in-differences, which represent project impacts (ATT).

Table 15 shows that HOPE increased the share of farmers using commercial channels to obtain sorghum seed, but the average treatment effect was small (0.4%). Among the treatment group, 39 % of households growing improved sorghum at baseline obtained seed from extension officers, compared to just 19 % of farmers in the control group. By the early adoption survey, this situation was reversed. Most households in the treatment group that grew improved sorghum (49 %) obtained seed from their own store, By contrast, 47 % of households in the control group still relied on extension officers and only 20 % used improved seed from their own store. Interestingly, the share of farmers obtaining improved seed through farmer-to-farmer exchange also rose among the treatment group. Thus, HOPE increased the use of farmer-to-farmer exchange by 12.5 % and reduced farmer reliance on extension officers for improved seeds by 7 %. However, there was no change in the use of commercial seed channels. From this analysis, we find treatment effects of 12.5 %, -7.2 % and -7.0 % for farmer-to-farmer exchange, extension officer and own-store seed sources respectively, implying that HOPE increased the use of farmer-to-farmer seed system and reduced farmer reliance on extension officers for improved seeds.

Due to the small sample of adopters in the matched sample, it was not possible to use regression analysis to assess the robustness and statistical significance of the treatment effects; hence these results should be interpreted with caution. Nevertheless, the extremely low and unchanging figures for use of commercial seed channels imply that Hypothesis 4 cannot be rejected.

4.4 Grain sales

Table 16 shows results commercialization of harvested sorghum and finger millet grain. Detailed results stratified by district and village cluster are presented in Table A9. For the sample as a whole, the share of farmers selling sorghum fell by 8 %, from 21 % at baseline to 13 % during the early adoption survey. There was no change in the average quantity sold per household. For finger millet, the share of growers selling remained constant at 75 % and there was no change in the average quantity sold.

Table 16: Difference-in-differences estimates for commercialization of sorghum and finger millet

	Sorghum			**Finger millet**		
	Baseline	Early Adoption	*Difference*	Baseline	Early Adoption	*Difference*
Market participation (% growers)[a]						
Total	20.7	12.6	*-8.1****	74.4	74.8	*0.4*
Treatment	16.0	6.7	*-9.3***	76.1	69.7	*-6.4*
Control	24.1	15.4	*-8.7***	73.1	81.1	*8.0*
Difference	*-8.1**	*-8.7***	***-0.6***	*3.0*	*-11.4*	***-14.4***
Quantity sold (kg)						
Total	62.0	93.0	*31.0*	32.6	37.7	*5.1*
Treatment	62.0	60.7	*1.3*	381.8	349.8	*-32.0*
Control	65.6	108.8	*43.2*	250.2	451.9	*201.7****
Difference	*-3.6*	*-48.1*	***-44.5***	*131.6**	*-102.1*	***-233.7***
Harvest sold (%)						
Total	10.5	6.2	-4.3**	61.4	80.9	19.5***
Treatment	9.1	5.1	*-4.0*	61.6	80.3	*18.7****
Control	11.6	7.0	*-4.6***	61.1	82.1	*21.0****
Difference	*-2.5*	*-1.9*	***-0.6***	*0.5*	*-1.8*	***-2.3***

Note: [a] market participation is calculation excludes farmers with zero harvest. *, **, *** difference between treatment and control groups or survey rounds is significant at 10%, 5% and 1% respectively, following t-tests. **Bold** figures are the mean difference-in-differences, which represent project impacts (ATT).

Among the treatment group, market participation among sorghum-growers fell by 9 %, from 16 % in 2009 to 7 % in 2012. Participation also fell among the control group, resulting in a small negative treatment effect of - 6 %. The quantity of sorghum sold did not change in the treatment group, but increased in the control group, resulting in a negative treatment effect of - 44.5 kg/household. The share of harvest sold fell slightly for both treatment and control groups, resulting in a treatment effect of - 0.6%. For finger millet, market participation in the treatment group fell, while increasing in the control group. This resulted in a negative treatment effect of -14.4%. Similarly, the average quantity sold per household fell in the treatment group while increasing in the control group, resulting in a large negative treatment effect of -234 kg/household. For both treatment and control groups, the share of harvest sold increased from 60% at baseline to 80% at the early adoption survey. The treatment effect on the share of finger millet harvest sold was - 2.3 %. Due to the low levels of sorghum commercialization and finger millet cultivation in the early-adoption survey, regression analysis was not used to obtain robust treatment effects. Nevertheless, the low treatment effects imply that generally we cannot reject the null hypothesis that HOPE had no significant impact on grain commercialization.

5. Discussion

HOPE hypothesised that the commercialization of sorghum and millets would provide farmers with the incentive to adopt new technology. In this section, we analyse the implications of our survey results for this Theory of Change.

5.1 Adoption

HOPE was successful in increasing the adoption of improved varieties. There was a large positive treatment effect (13.2%) on the share of farmers adopting improved sorghum, and on the share of the area planted to improved varieties (6.7%) (Table 7). Similar results were found for the HOPE project in Mali, where the average treatment effect for the share of farmers adopting improved sorghum and pearl millet varieties was 15% (Badalo, 2012). In both countries, higher adoption was linked to the distribution of Small Seed Packs (SSPs) which created awareness of improved varieties and provided farmers with access to seed. [7] While HOPE increased the uptake of improved seed, however, the impact on adoption, which is a longer-term process, is less clear. This will depend on whether farmers are willing to pay the market price for certified seed and whether they will continue to have access to improved seed through other channels after the end of the project.

5.2 Yields

HOPE based its assumption of productivity gains on the synergy between improved varieties and crop management practices, because 'it is difficult to boost yields with improved varieties alone on the nutrient-depleted soils of dryland Africa' (ICRISAT, 2009: 4). Although HOPE was successful in increasing the average yield of sorghum, the treatment effect was miniscule (0.003 tons ha-1). Moreover, this increase did not come from improved varieties, which showed no significant change in yields, but from local varieties which showed a significant increase in yields. Indeed, in the second survey round, 'improved' varieties showed no yield advantage over local varieties. Consequently, the increase in adoption of improved varieties was not matched by any gains in productivity.

One likely reason for the low yields from improved varieties was that farmers did not follow the improved crop agronomic practices recommended by the HOPE project (Table 13). These practices included micro-dosing with inorganic fertilizer and water management through mulching and tied ridging. Low uptake reflected low profitability. The APSIM model calibrated for sorghum in central Tanzania (Dodoma) showed that for the improved variety Macia, 30 kg N ha-1 gave the optimum yield, but that for more than half the time the benefit-cost ratio did not exceed 2 (Dixit, 2012: 20). Similarly, partial budget analysis of on-farm trials in Dodoma showed that micro-dosing with Macia gave the highest net returns ($261 ha-1), but that this was only $29 ha-1 higher than planting local sorghum without inorganic fertilizer (Orr and Mwema, 2012).8 Moreover, neither mulching nor tied ridging had any benefits. The APSIM model showed that mulching and tied ridging had no effect on yields

[7] A separate study of the effectiveness of Small Seed Packs in central Tanzania is in preparation.

[8] Results for Tanzania were available for one trial only and for a single season (2011 long rains).

(Dixit, 2012) while on-farm trials showed negative benefits from tied ridging because of high labour requirements (Orr and Mwema, 2012). In these circumstances, farmers' reluctance to adopt 'improved' crop management seems rational.

5.3 Commercial seed channels

HOPE hypothesized that increased awareness of improved varieties would stimulate demand for certified seed that would result in the growth of commercial seed sales for sorghum and millets. However, our results showed that HOPE did not increase demand from commercial channels, which accounted for just 2 % of supply (Table 15). Instead, farmers in the treatment group who grew improved varieties of sorghum switched from reliance on extension officers to their own saved seed. Meanwhile, extension officers became the main source of improved seed for farmers in the control group. Throughout the project, therefore, the main source of improved seed was the extension service, which first supplied farmers in treatment areas before supplying farmers in control areas.

Private companies find Open Pollinated Varieties (OPVs) unprofitable because farmers' practice of re-cycling seed reduced market demand. Although HOPE increased the share of farmers adopting improved varieties of sorghum by 15%, farmers reported recycling seed every three years (Schipmann, 2012), which means that demand for certified seed would increase by only 5 % per annum. Moreover, this assumes that farmers had no other sources of supply, but the free distribution of Small Seed Packs by the project, a government subsidy scheme for sorghum in 2012, the availability of Quality Declared seed (QDS) from other farmers, as well the doubling of farmer-to-farmer exchange noted within the treatment group, would all have dampened the market for commercial seed companies.

5.4 Grain sales

HOPE hypothesized that higher yields would allow more farmers to participate in markets and increase the volume of grain they sold.

This argument is untenable for sorghum. In the same period that the share of farmers adopting improved sorghum varieties rose by 15 %, the share of farmers selling sorghum dropped by 13 %, and less than 5 % of the harvest was sold. Sorghum was primarily a food crop. By contrast, finger millet was primarily a cash crop. Before the start of the project, market participation was already 75 % and 60 % of the harvest was sold (Table 16). HOPE's impact on the commercialization of finger millet was puzzling, showing negative treatment effects on both market participation (-14.4 %) and on the average quantity sold (-234 kg/household). One explanation is that finger millet had become less competitive as a cash crop. At baseline, 81% of farmers in the treatment area grew finger millet compared to just 59 % in the control area. Three years later, the share of treatment farmers growing finger millet in the treatment area had dropped to 33 %, or 10 % less than in the control area. In the same period the share of farmers in the treatment group growing sunflower rose by 26 % (Table 9). This suggests that sunflower was replacing finger millet as a cash crop. According to farmers, this process was already underway before the baseline survey in 2012 (Schipmann, 2012). Commercialisation was therefore a two-edged sword, which could work against dryland cereals if they became less competitive with other cash crops.

HOPE's experience with sorghum shows that 'market-pull' is not essential for the adoption of improved varieties. This is nothing new. Reviewing results from the SADC/ICRISAT Sorghum and Millets Improvement Program (SMIP), which in 15 years released 40-plus improved varieties of sorghum and millets, an ICRISAT economist concluded:

'The main contribution of these new varieties is early maturity. Farmers commonly note that when rains are favorable, the new varieties offer only small yield advantages over their traditional medium- and late-maturing varieties. However, when rains are poor, the new varieties offer the possibility of a harvest, or a large increase in grain yield. Thus, the most important contribution of these new varieties has been to household food security' (Rohrbach, 2003: 7).

A previous adoption survey in Tanzania showed that the two traits of improved sorghum varieties ranked highest by farmers were early maturity and drought tolerance. Early-maturing varieties provided food in the hungry period before the next harvest, when the majority of households had run out of grain, and also ensured that at least some grain was harvested in years when the rains ended early (Monyo et al. 2004: 15).9 Hence, the absence of a market was no bar to farmers adopting improved varieties.

HOPE's objective was not simply to increase the adoption of improved varieties, but to enhance productivity. By framing the problem as one of productivity, and in the knowledge that increasing productivity would require investment in improved crop management, HOPE had to address the issue of incentives. Based on the assumption that farmers will usually invest cash only where they see a cash return, HOPE's solution was to link increasing productivity with market demand. Commercialization of sorghum and millets would provide farmers with the cash incentive to make the necessary investment required to raise productivity.

What evidence did HOPE produce to support this Theory of Change? The higher rate of manure applied to finger millet (4 tons ha-1) – a cash crop – than to sorghum (3.5 tons ha-1) – a food crop – at baseline suggests that farmers did invest more where they saw a commercial return (Schipmann et al. 2013: 19). Farmers also planted finger millet on more fertile soils than sorghum (Schipmann, 2012). But the early adoption survey showed no significant change in the rate of manure applied to finger millet between 2009 and 2012, although there was a rise in the share of farmers applying manure. Moreover, no farmers applied inorganic fertilizer to finger millet (Table 13). Similarly, farmers in Kenya who adopted Gadam sorghum to supply the market for sorghum beer did not adopt improved management practices such as inorganic fertilizer or chemical crop protection (Orr et al. 2013: 35). Consequently, there is little evidence to support the argument that commercialization of dryland cereals would stimulate investment to raise productivity.

More broadly, the contrast between sorghum and finger millet in central Tanzania highlights the importance of the local context in determining the opportunities for commercialization. In Ethiopia, the roles of sorghum and finger millet were reversed. The HOPE baseline survey

[9] The improved sorghum varieties promoted by the HOPE project included Macia, which was early to medium duration (115-120 days to maturity) and Pato, which was medium to late duration (130-140 days) (Monyo et al. 2004: 20-21).

showed that in the two project areas in Miesso and Kobo districts, 32 % of sorghum was sold and 55% was kept for home consumption, whereas in the project area of Shalla district, 88 % of finger millet was kept for home consumption and only 13 % was sold (Bekele et al. 2012: 36-37). The commercialization of sorghum reflected demand from the Afar, pastoralists who relied on market purchases for household food security. Hence, the potential for commercialization varied by crop and by country.

5.5 Re-thinking HOPE's Theory of Change

Our findings challenge HOPE's Theory of Change on several levels. HOPE saw commercialization as the main incentive for the adoption of new technology. The focus on increasing cash income aligned ICRISAT's research with the Millennium Development goal to halve income poverty by 2015, while the focus on markets as the key to development reflected the entrepreneurial origins of the BMGF which funded the HOPE project[10]. HOPE applied this commercialization model universally to 11 countries in two continents. The danger of this universal model was that it ignored the diversity of market development between these countries, as well as the different roles that sorghum and millet could play in the farming system. In retrospect, this was a mistake. Rather than drive adoption by attempting to create 'market-pull' where none existed, it would have been wiser to identify whether farmers in specific regions required improved varieties for food security or for markets, and to provide new technology that met those needs.

Our findings also challenge a major assumption in HOPE's Theory of Change. Although HOPE successfully increased farmer awareness and adoption of improved varieties, there was no corresponding gain in productivity. Average yields from improved varieties did not differ significantly from local varieties in both survey rounds. This highlights the importance of improved crop management. However, in central Tanzania the incentive to adopt these technologies was weak. Of the technologies available, only micro-dosing with inorganic fertilizer was profitable. Again, this shows the importance of the local context in determining the incentives for adoption of specific technologies.

Based on this evidence, a revised Theory of Change for dryland cereals in ESA would include the following elements:

1. A pluralistic model that set research priorities for dryland cereals according to farmers' own objectives for food security and/or cash income, avoiding the imposition of a universal 'market-pull' model;
2. Targeted market-led innovation where strong market demand already exists, avoiding the need for value chain development *de novo*;
3. Crop management technologies that improved productivity *and* profitability of dryland cereals under farmers' management and field conditions, rather than assuming productivity gains following the adoption of improved varieties.
4. Active promotion of commercial seed channels to ensure access to improved seed after the project ends, rather than assuming that creating demand will automatically stimulate supply from agro-dealers.

[10] In 2009 the BMGF accounted for 15 % of ICRISAT's total budget, making it ICRISAT's largest single donor (ICRISAT, 2009: 25). The BMGF's budget for the HOPE Project was $18.14 million.

6. Conclusion

Experience with the HOPE project in central Tanzania suggests that ICRISAT needs to change its Theory of Change for dryland cereals. This should be seen in a positive light as a learning outcome from the project.

A universal Theory of Change based on market-pull overlooks the diversity within the same region let alone between continents. This diversity is reflected both in the level of market development and the role that sorghum and millets play in the farming system. In ESA, Kenya has a well-developed processing industry while in Ethiopia most households process their own flour. In Tanzania, sorghum is a food crop and finger millet is a cash crop, while in Ethiopia the reverse is true. Viewing these crops solely in terms of their market potential overlooks their importance for household food security, for managing downside risk in drought years, and feeding livestock that are essential for draught power, milk, and manure. As experience with sorghum in Tanzania shows, markets are not essential to drive the adoption of new technology. Improving household food security can be an equally strong incentive for farmers to adopt improved varieties that shorten the hungry period and escape late-season drought.

Dryland cereals in ESA therefore require a pluralistic Theory of Change that captures these differences in farmers' production objectives and in market demand between countries. This will need accurate information on the utilization of dryland cereals, the major sources of market demand, and the scale of this demand. Only then will it be possible to develop a realistic Theory of Change for the region.

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Appendix

Table A-1: Covariate balancing before and after matching

Variable	Unmatched/ Matched	Mean		% bias reduction	t-test
		Treated	Control		t-value
Age	Unmatched	45.59	43.78		1.44
	Matched	45.89	45.65	87.1	0.18
Female	Unmatched	0.152	0.132		0.53
	Matched	0.140	0.136	76.9	0.12
Muslim	Unmatched	0.673	0.454		4.18***
	Matched	0.659	0.684	88.3	-0.49
Hhsize	Unmatched	6.620	6.305		1.30
	Matched	6.598	6.475	61.3	0.49
Radio	Unmatched	0.778	0.833		-1.30
	Matched	0.787	0.793	88.8	-0.14
Mobile	Unmatched	0.538	0.454		1.56
	Matched	0.524	0.501	72.1	0.42
Oxplough	Unmatched	0.228	0.253		-0.54
	Matched	0.232	0.223	64.3	0.19
Bicycle	Unmatched	0.626	0.609		0.32
	Matched	0.622	0.612	38.0	0.19
Association	Unmatched	0.257	0.368		-2.22**
	Matched	0.268	0.283	86.9	-0.29
Infonet	Unmatched	2.737	3.109		-2.20**
	Matched	2.805	2.781	93.5	0.14
Adminlink	Unmatched	14.54	13.05		1.45
	Matched	14.26	13.87	65.8	0.48
Livestock	Unmatched	0.635	0.874		-1.88*
	Matched	0.652	0.581	70.2	0.64
Kondoa	Unmatched	0.515	0.500		0.27
	Matched	0.518	0.517	92.3	0.02

Table A-2: Changes in awareness and adoption of improved varieties by district and village cluster

Awareness/	Kondoa			Singida Rural			Treatment areas			Overall		
Adoption	*Treatment*	*Diffusion*	*Control*	*Treatment*	*Diffusion*	*Control*	*Treatment*	*Diffusion*	*Control*	*Kondoa*	*Singida*	*Sample*
Awareness (% sample)												
Early-Adoption	92.0	91.1	78.6	67.5	60.5	91.1	80.1	76.1	85.0	88.6	71.9	*80.3*
Baseline	53.3	66.7	68.9	35.6	42.2	37.8	44.4	54.4	53.3	60.6	37.8	*49.2*
Difference	*38.7****	*24.4****	*9.7*	*31.9****	*18.3***	*53.3****	*35.7****	*21.7****	*31.7****	*28.0****	*34.1****	*31.1****
Awareness intensity (no. of varieties)												
Early-Adoption	2.10	2.11	1.33	1.48	1.09	1.57	1.80	1.61	1.45	1.92	1.40	*1.67*
Baseline	1.03	1.13	1.13	0.57	0.56	0.69	0.80	0.84	0.91	1.08	0.59	*0.84*
Difference	*1.07****	*0.98****	*0.20*	*0.91****	*0.53****	*1.12****	*1.00****	*0.77****	*0.54****	*0.84****	*0.81****	*0.83****
Adoption rate (% growers)												
Early-Adoption	53.1	44.7	25.0	50.0	44.4	47.5	51.0	44.6	36.4	40.2	47.9	*44.5*
Baseline	41.7	57.8	24.3	11.1	22.7	2.6	24.3	46.3	13.3	42.6	10.5	*26.9*
Difference	*11.5*	*-13.0*	*0.7*	*38.9****	*21.7***	*44.9****	*26.7****	*1.7*	*23.1****	*2.4*	*37.4****	*17.6****
Adoption intensity (% sorghum area)												
Early-Adoption	45.7	31.5	10.5	28.5	31.1	26.4	34.3	31.4	18.7	28.5	28.6	*28.6*
Baseline	38.5	41.1	13.7	8.1	8.6	0.3	21.2	30.5	6.7	32.5	5.7	*19.4*
Difference	*7.2*	*-9.6*	*-3.2*	*20.4****	*22.5****	*26.1****	*13.1***	*0.9*	*12.0****	*-4.02*	*22.9****	*9.2****

Note: Adoption intensity includes zero values for non-adopters. *, **, ***, change is significant at 10%, 5% and 1%, respectively based on a *z* or *t*-test.

Table A-3: Changes in proportion of farmers cultivating key crops (% sample)

Crop/survey round	Kondoa			Singida Rural			Treatment areas			Overall		
	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Kondoa	Singida	*Sample*
Sorghum												
Early-Adoption	36.3	84.4	88.1	77.1	83.7	88.9	56.1	84.1	88.5	61.1	81.9	71.4
Baseline	53.3	100	80	70.0	48.9	86.7	61.6	74.5	83.3	71.6	68.9	70.3
Difference	-17.0**	-15.6***	8.1	7.1	34.8***	2.2	-5.5	9.6*	5.2	-10.5**	13.0***	1.1
Finger millet												
Early-Adoption	38.6	6.7	9.5	47.0	32.6	44.4	42.7	19.3	27.6	23.4	42.7	32.9
Baseline	71.1	42.2	33.3	94.5	84.5	75.5	82.8	63.3	54.5	54.4	87.2	70.8
Difference	-32.5***	-35.6***	-23.8***	-47.5***	-51.9***	-31.1***	-40.1***	-44.0***	-26.9***	-31.0***	-44.5***	-37.9***
Pearl millet												
Early-Adoption	34.1	11.1	50.0	42.2	65.1	17.8	38.0	37.5	33.3	32.0	41.5	36.7
Baseline	33.3	28.9	73.3	45.6	75.5	55.6	39.4	52.2	64.4	42.2	55.5	48.9
Difference	0.8	-17.8**	-23.3**	-3.4	-10.4	-37.8***	-1.4	-14.7**	-31.1***	-10.2**	-14.0***	-12.2***
Maize												
Early-Adoption	97.7	97.8	83.3	75.9	83.7	93.3	87.1	90.9	88.5	94.3	82.5	88.4
Baseline	84.4	97.8	66.7	42.2	37.8	84.4	63.3	67.8	75.5	83.3	51.7	67.5
Difference	13.3***	0.0	16.7**	33.7***	45.9***	8.9*	23.8***	23.1***	13.0**	11.0***	30.8***	20.9***
Sunflower												
Early-Adoption	65.9	57.8	52.4	53.0	39.5	64.4	59.6	48.9	58.6	60.6	52.6	*56.7*
Baseline	34.4	46.7	31.1	26.7	28.9	44.4	30.6	37.8	37.8	36.7	31.7	*34.2*
Difference	*31.5****	*11.1*	*21.3***	*26.3****	*10.6*	*20.0***	*29.0****	*11.1**	*20.8****	*23.9****	*20.9****	*22.5****

*, **, *** Difference is significant at 10%, 5% and 1% respectively. Area allocations include zero values for non-growers of each crop.

Table A-4: Changes in area planted to key crops (ha/household)

Crop/survey round	Kondoa			Singida Rural			Treatment areas			Overall		
	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Kondoa	Singida	*Sample*
Sorghum												
Early-Adoption	0.24	1.03	0.85	0.79	0.49	1.35	0.51	0.77	1.11	0.59	0.86	0.72
Baseline	0.35	1.25	0.60	0.60	0.29	0.86	0.48	0.76	0.73	0.64	0.59	0.61
Difference	-0.11*	-0.23	0.25**	-0.19	0.20**	0.49***	0.03	0.01	0.38***	-0.05	0.27***	0.11*
Finger millet												
Early-Adoption	0.30	0.04	0.03	0.39	0.17	0.38	0.34	0.10	0.21	0.17	0.33	0.25
Baseline	0.62	0.55	0.18	1.10	0.46	0.76	0.86	0.51	0.47	0.49	0.85	0.67
Difference	-0.32***	-0.51***	-0.15***	-0.71***	-0.29***	-0.38**	-0.52***	-40.1***	-0.26**	-0.32***	-0.52***	-0.42***
Pearl millet												
Early-Adoption	0.23	0.12	0.37	0.30	0.34	0.13	0.26	0.23	0.25	0.24	0.27	0.25
Baseline	0.33	0.28	0.77	0.29	0.42	0.34	0.31	0.35	0.55	0.43	0.33	0.38
Difference	-0.10	-0.16	-0.40**	0.01	-0.08	-0.19**	-0.04	-0.12*	-0.30***	-0.19***	-0.06*	-0.13***
Maize												
Early-Adoption	1.11	1.69	0.68	0.58	0.42	0.88	0.86	1.06	0.78	1.15	0.62	0.89
Baseline	1.32	1.84	0.57	0.31	0.17	0.93	0.82	1.00	0.75	1.26	0.43	0.85
Difference	-0.21	-0.15	0.11	0.27**	0.25***	-0.05	0.04	0.06	0.03	-0.11	0.19**	0.04
Sunflower												
Early-Adoption	0.66	0.93	0.50	0.48	0.29	1.16	0.57	0.62	0.84	0.69	0.61	*0.65*
Baseline	0.38	0.64	0.26	0.22	0.17	0.58	0.30	0.41	0.42	0.41	0.30	*0.35*
Difference	*0.28**	*0.29*	*0.24***	*0.26****	*0.12*	*0.58**	*0.27****	*0.21*	*0.42***	*0.28***	*0.31****	*0.30****

*, **, *** Difference is significant at 10%, 5% and 1% respectively. Area allocations include zero values for non-growers of each crop.

Table A-5: Changes in production of sorghum by district and village cluster

Productiion	Kondoa			Singida Rural			Treatment areas			Overall		
	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Kondoa	Singida	Sample
Total production (tons)												
Early-Adoption	0.387	0.659	0.492	0.476	0.476	0.949	0.445	0.569	0.724	0.517	0.598	0.563
Baseline	0.308	0.483	0.278	0.388	0.450	0.490	0.353	0.473	0.388	0.363	0.429	0.395
Difference	*0.079*	*0.176*	*0.214*	*0.088*	*0.026*	*0.459****	*0.092*	*0.096*	*0.337****	*0.154***	*0.169***	*0.168****
Improved variety production (tons)												
Early-Adoption	*0.367*	*0.450*	*0.060*	*0.240*	*0.224*	*0.354*	*0.285*	*0.341*	*0.256*	*0.340*	*0.266*	*0.295*
Baseline	*0.274*	*0.465*	*0.161*	*0.219*	*0.203*	-	*0.259*	*0.428*	*0.161*	*0.354*	*0.213*	*0.328*
Difference	*0.093*	*-0.015*	*-0.101***	*0.021*	*0.021*	-	*0.026*	*-0.087*	*0.095*	*-0.014*	*0.053*	*-0.033*

Note: *, **, *** Differences between baseline and early-adoption figures are significant at 10%, 5% and 1% respectively. Missing values: no harvest reported.

Table A-6: Changes in sorghum yields by district and village cluster

Productivity	Kondoa			Singida Rural			Treatment areas			Overall		
	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Kondoa	Singida	Sample
Overall yields (tons ha^{-1})												
Early-Adoption	0.58	0.63	0.57	0.60	0.84	0.68	0.60	0.74	0.63	0.60	0.69	0.65
Baseline	0.55	0.64	0.42	0.43	0.75	0.54	0.49	0.68	0.48	0.55	0.52	0.54
Difference	*0.03*	*-0.01*	*0.15*	*0.17****	*0.09*	*0.14*	*0.11**	*0.06*	*0.15*	*0.05*	*0.17****	*0.11***
Improved variety yields (tons ha^{-1})												
Early-Adoption	*0.53*	*0.96*	*0.20*	*0.57*	*0.56*	-	*0.57*	*0.77*	*0.46*	*0.63*	*0.58*	*0.60*
Baseline	*0.60*	*0.84*	*0.31*	*0.58*	*0.72*	-	*0.60*	*0.82*	*0.31*	*0.68*	*0.63*	*0.67*
Difference	*-0.07*	*0.12*	*-0.11*	*-0.01*	*-0.16*	-	*-0.03*	*-0.05*	*0.15*	*-0.05*	*-0.05*	*-0.07*

Note: *, **, *** Differences between baseline and early-adoption figures are significant at 10%, 5% and 1% respectively

Table A-7: Changes in crop management practices by district and village cluster

Crop management practice	Kondoa			Singida Rural			Treatment areas			Overall		
	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Kondoa	Singida	Sample
Sorghum manure (tons ha^{-1})												
Early-Adoption	3.3	0.0	0.0	5.4	2.9	3.6	4.7	2.9	4.5	5.5	3.9	4.3
Baseline	10.9	4.9	8.0	2.8	6.8	8.4	7.5	6.5	8.3	10.1	6.3	7.5
Difference	*-7.6**	*-4.9*	*-8.0*	*2.6**	*-3.9***	*-4.8***	*-2.8*	*-3.6***	*-3.8**	*-4.6*	*-2.4**	*-3.2***
Sorghum manure(% farmers)												
Early-Adoption	25.0	0.0	15.6	21.3	38.2	57.6	22.6	18.8	36.9	13.1	35.1	25.6
Baseline	15.2	0.0	0.0	8.6	19.0	15.6	11.5	6.3	7.9	5.9	12.6	9.1
Difference	*9.8*	*0.0*	*15.6****	*12.7***	*19.2**	*42.0****	*11.1***	*12.5***	*29.0****	*7.2***	*22.5****	*16.4****
Sorghum Seed Treatment (% farmers)												
Early-Adoption	0.0	5.9	3.0	10.0	8.6	15.2	6.5	7.2	9.1	3.0	10.9	7.5
Baseline	0.0	7.1	6.5	5.2	4.8	0.0	2.9	6.3	3.2	4.2	3.6	3.9
Difference	0.0	-1.2	-3.5	4.8	3.8	15.2**	3.6	0.9	5.9*	-1.2	7.3**	3.6**
Finger millet manure(tons ha^{-1})												
Early-Adoption	2.0	0.0	0.0	7.5	9.5	0.25	5.6	9.5	0.2	2.0	7.4	6.1
Baseline	7.0	0.9	0.7	1.1	6.8	11.4	5.3	4.8	7.8	5.2	6.4	5.8
Difference	*-5.0*	*-0.9*	*-0.7*	*6.4*	*2.7*	*-11.15*	*0.3*	*4.7*	*7.6*	*-3.2*	*1.0*	*0.3*
Finger millet manure (% farmers)												
Early-Adoption	15.2	0.0	0.0	17.9	21.4	5.9	16.7	17.6	4.8	12.5	15.7	14.5
Baseline	11.7	0.0	7.7	5.4	4.6	3.4	8.2	3.8	4.8	8.8	5.1	6.5
Difference	*3.5*	*0.0*	*-7.7*	*12.5***	*16.8***	*2.5*	*8.5***	*13.9***	*0*	*3.7*	*10.6****	*8.0****
Finger millet Seed Treatment (% farmers)												
Early-Adoption	0.0	0.0	0.0	5.0	7.7	0.0	2.7	6.2	0.0	0.0	4.3	2.7
Baseline	0.0	5.6	0.0	0.0	2.9	0.0	0.0	3.8	0.0	1.1	0.7	0.9
Difference	*0.0*	*-5.6*	*0.0*	*5.0***	*4.8*	*0.0*	*2.7***	*2.4*	*0.0*	*-1.1*	*3.6***	*1.8**

Note: Analysis of manure and seed treatment adopters is based on sample of growers, while manure use rate is based plot-level data. *, **, *** Differences between baseline and early-adoption figures are significant at 10%, 5% and 1% respectively.

Table A-8: Changes in sources of improved sorghum seed by district and village cluster (% farmers)

Seed source	Kondoa			Singida Rural			Treatment areas			Overall		
	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Kondoa	Singida	Sample
Farmer-to-farmer exchange												
Early-Adoption	11.8	0.0	22.2	15.6	18.8	100	14.3	9.1	7.1	9.3	11.9	10.9
Baseline	0.0	7.7	22.2	28.6	40.0	0.0	7.4	12.9	30.0	7.3	38.4	13.2
Difference	*11.8**	*-7.7*	*0.0*	*-13.0*	*-21.2*	*100*	*6.9*	*-3.8*	*-22.9***	*2.0*	*-26.5****	*-2.3*
Extension Officers												
Early-Adoption	17.6	*52.9*	*0.0*	*18.8*	*43.8*	26.3	*18.3*	*48.5*	*0.17.9*	*27.9*	*26.9*	*27.3*
Baseline	50.0	*50.0*	*66.7*	*14.3*	*0.0*	0.0	*40.7*	*41.9*	*60.0*	*52.7*	*7.7*	*44.1*
Difference	*-32.4***	*2.9*	*-66.7****	*4.5*	*43.8***	*26.3*	*-22.4***	*6.5*	*-42.1****	*-24.8****	*19.2**	*-16.8****
Own storage												
Early-Adoption	64.7	35.3	66.7	53.1	31.3	47.4	57.1	33.3	53.6	53.5	46.3	49.1
Baseline	35.0	30.8	11.1	57.1	0.0	0.0	40.7	25.8	10.0	29.1	30.8	29.4
Difference	*29.7***	*4.5*	*55.6****	*4.0*	*31.3**	*0.0*	*16.4**	*7.5*	*43.6****	*24.4****	*15.5*	*19.7****
Commercial seed channels												
Early-Adoption	0.0	0.0	0.0	*6.3*	0.0	0.0	*4.1*	0.0	0.0	*0.0*	*3.0*	*1.8*
Baseline	10.0	0.0	0.0	*0.0*	0.0	0.0	*7.4*	0.0	0.0	*3.6*	*0.0*	*2.9*
Difference	*-10.0**	*0.0*	*0.0*	*6.3*	*0.0*	*0.0*	*-3.3*	*0.0*	*0.0*	*-3.6*	*3.0*	*-1.1*

Note: *, **, ***: baseline and early-adoption survey figures differ significantly at 10%, 5% and 1%, respectively based on a z-test.

Table A-9: Changes in sorghum commercialization by district and village cluster

Crop/survey round	**Kondoa**			**Singida Rural**			**Treatment areas**			**Overall**		
	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Treatment	Diffusion	Control	Kondoa	Singida	*Sample*
Sorghum												
Market participation (%growers)												
Early-Adoption	14.3	22.9	8.1	4.7	11.1	21.0	7.6	16.9	14.7	15.0	10.8	*12.6*
Baseline	25.5	40.5	30.3	8.3	9.1	10.8	15.9	29.7	20.0	32.0	9.2	*20.7*
Difference	*-11.2*	*-17.6***	*-22.2***	*-3.6*	*2.0*	*10.2*	*-8.3***	*-12.8***	*-5.3*	*-17.0****	*-1.6*	*-8.1****
Quantity (tons) sold												
Early-Adoption	0.154	0.104	0.136	0.036	0.026	0.154	0.072	0.065	0.145	0.130	0.066	*0.093*
Baseline	0.057	0.125	0.080	0.062	0.008	0.013	0.060	0.085	0.044	0.087	0.036	*0.062*
Difference	*0.097**	*-0.021*	*0.056*	*-0.026*	*0.018*	*0.141***	*-0.012*	*-0.020*	*0.101*	*0.043*	*0.030*	*0.031*
Finger Millet												
Market participation (%growers)												
Early-Adoption	71.4	66.7	75.0	69.2	85.7	84.2	70.0	82.4	82.6	71.4	76.4	*74.8*
Baseline	67.2	50.0	50.0	82.3	89.5	73.5	76.0	76.8	66.7	61.3	82.2	*74.4*
Difference	*4.2*	*16.7*	*25.0*	*-13.1***	*-3.8*	*10.7*	*-6.0*	*5.6*	*15.9**	*10.1*	*-5.8*	*0.4*
Quantity (tons) sold												
Early-Adoption	0.278	0320	0.135	0.392	0.461	0.486	0.345	0.436	0.425	0.266	0.431	*0.377*
Baseline	0.311	0.228	0.070	0.430	0.316	0.260	0.380	0.288	0.204	0.259	0.365	*0.326*
Difference	*-0.033*	*0.092*	*0.065*	*-0.037*	*0.145**	*0.226**	*-0.035*	*0.149***	*0.221***	*0.007*	*0.066*	*0.051*

Note: *, **, *** Differences between baseline and early-adoption figures are significant at 10%, 5% and 1% respectively.