Do the Benefits of Improved Management Practices to Nutritional Outcomes "Dry Up" in the Presence of Drought? Evidence from East Africa

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Keywords: Dietary Diversity, Food Security, Africa, Farm Production, Drought

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Abstract

Using a panel of nearly 3,000 agricultural households in Tanzania and Mozambique from 2016-2018, this paper investigates the associations of nutritional outcomes and agricultural management practices under drought risk. We show drought has significant consequences on two nutritional outcomes in particular: food security and dietary diversity. Importantly, these consequences are evident even for households using improved management practices, such as improved seed, chemical fertilizer, and production diversity. This finding has important implications in the context of how policy makers use the tools at their disposal – including both promotion of improved agricultural management practices and direct transfers – to prevent costly coping strategies that reduce future resilience.

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1 Introduction

Nutrition persists as one of the most pressing issues for farmers in East Africa. Smallholder and rain-fed farms account for the majority of farmland in the region (Sheahan and Barrett, 2017) and the ever-present threat of crop failure creates high levels of uncertainty for both households and the governments that serve them. Drought, in particular, is an increasing concern. Drought years have been shown to have large negative effects on food availability, quantity, and quality, leading to costly coping mechanisms (Wineman et al., 2017; Carter and Lybbert, 2012; Janzen and Carter, 2019). While governments and non-governmental organizations seek to offset these effects, emergency assistance is often slow and expensive. Increasingly, policy and investments are made for the creation and promotion of management practices that can help shore up nutritional security.

In order to create evidence-based food and agricultural policy for East Africa, it is important to understand whether the beneficial relationship between best management practices and nutritional outcomes is primarily apparent in "good" (non-drought) years or in "bad" (drought) years. While strategies associated with improved nutritional outcomes in non-drought years are beneficial, they may do little to foster resilience or displace the need for emergency assistance during drought years. If, on the other hand, outcomes are improved primarily through a reduction in negative effects of drought on nutrition, then the creation and promotion of better management practices can be viewed as an investment in the resilience of smallholder farmers in regions where rain-fed agriculture is prominent.

We use household-level panel data from Tanzania and Mozambique to study the relationship between management practices and nutritional outcomes, with particular attention to how that relationship is mediated by drought. Specifically, this paper reports on three management practices that are common tenets of agricultural policies: use of improved seed varieties, use of chemical fertilizers, and on-farm production diversity. For each management practice, we present evidence on its association with two facets of household nutrition:

dietary diversity and food security outcomes.

This paper contributes to the literature in three ways. First, we contribute to the literature documenting the potential benefits of management practices and the harmful nature of drought on nutritional outcomes. We find that, on average and as expected, improved management practices are associated with more diverse diets, higher probabilities of food security, and less severe food insecurity. The associations are particularly strong for use of improved maize seed varieties and production diversity. Next, we contribute an investigation of whether the positive relationship between management practices and nutritional outcomes is concentrated only in good years or is also present in drought years. We find that positive associations exist in both drought and non-drought years, which is encouraging. At the same time, the reduction in outcomes associated with drought is still larger than the increase in outcomes associated with management practices. As such, the allocation of resources between emergency assistance and promotion of improved management practices will continue to be an important policy decision for those seeking to improve resilience. On our way to this result, we also contribute to the literature on nutritional outcomes among farm households by documenting the imperfect overlap between dietary diversity and food security measures.

The paper proceeds as follows; first, we provide an overview of the context and literature that frame our work. The following sections lay out the methodology and data used in our analysis of nutritional outcomes, management practices, and drought. Section 3 contains our primary analysis, demonstrating the association between management practices and nutritional outcomes in drought and non-drought years. We conclude with a discussion of the implications of these results for farm-household resilience and agricultural policy.

1.1 Background

Nutritional failures in the early years of life can have long-term consequences on health and development (Alderman, Hoddinott and Kinsey, 2006; Hoddinott and Kinsey, 2001). These consequences can stem from households pursuing strategies to deal with shocks to agricultural production and income that do not completely provide the nutrition necessary for growth and development. Shocks that affect entire communities, in particular, are more likely to have long-term consequences than idiosyncratic shocks that can be mediated by community-level informal insurance (Carter and Maluccio, 2003).

Drought is, perhaps, the prototypical community-level shock. Not only does drought directly affect households' agricultural production, but the threat of drought may induce households to reduce current consumption in order to protect productive assets viewed as critical for longer term economic and food security (Carter and Lybbert, 2012; Janzen and Carter, 2019). More vulnerable households may also choose conservative management practices (Alderman and Paxson, 1994; Deaton, 1989) – increasing precautionary savings (Zimmerman and Carter, 2003; Lee and Sawada, 2010), or diversifying production into more drought-resistant staple crops (Barnett, Barrett and Skees, 2008) – in order to ensure that they can obtain sufficient calories even in years characterized by drought.

With climate change predicted to increase the frequency and severity of drought events, particularly in Africa (Niang et al., 2014), protecting households' economic and nutritional security is of increasing importance. Improved agricultural management practices are often central tenets of this effort and of agricultural policy in the region more broadly (Ariga et al., 2019; Sasson, 2012). Adoption of these practices can have both a level effect (increased average yields) and a stabilizing effect (reduced yield variation) on production (Rusinamhodzi et al., 2012; Fisher et al., 2015; Koussoubé and Nauges, 2017).

Three management practices, in particular, are relevant for the analysis conducted in this paper: use of improved seed varieties, use of chemical fertilizer, and production diversity. Jayne and Rashid (2013) report that in 2011, ten countries in Africa were spending over a billion dollars each – on the order of 30% of their public agricultural budget – on input subsidies[1]. Public research dollars have similarly been poured into developing and promoting inputs with an eye to improving income and food security. In terms of improved seed use,

[1] Relevant to the current paper, Jayne and Rashid (2013) report that input subsidies accounted for 38.5%, 53.5%, and 46% of Tanzania's public agricultural spending in 2009, 2010, and 2011 respectively.

we focus on maize, which is a primary staple crop both in the region and for the sample of households studied here.

Increased adoption of improved seed varieties – certified seed varieties produced using selective breeding to display desirable traits such as increased synchronization of pollination – in sub-Saharan Africa is one approach to improving livelihoods and managing vulnerability to drought (Shiferaw et al., 2014*a*; Kassie et al., 2015). Drought tolerant staple crops, maize among them, have been a focus of policy makers and non-governmental agencies for decades (CIMMYT, 2012; Fisher et al., 2015; Shiferaw et al., 2014*b*). The International Center for the Improvement of Maize and Wheat (CIMMYT) Drought Tolerant Maize for Africa (DTMA) program released 233 drought-tolerant maize varieties across thirteen countries between 2007 - 2015, with the explicit goal of raising incomes and strengthening food security (Abate et al., 2015). These investments have been estimated to generate billions of dollars of benefits by raising the level of and stabilizing maize yields (Kostandini et al., 2009; Kostandini, La Rovere and Abdoulaye, 2013). Less evidence exists on how these agricultural practices and outcomes map into nutritional outcomes.

Chemical fertilizers, as well, have often been the target of input subsidies, with varied evidence of success. Often, the costs of the programs seem to outweigh the benefits in the context of food prices and poverty rates, despite modest increases in yield (Jayne and Rashid, 2013; Jayne et al., 2018; Ricker-Gilbert, 2020). Mixed evidence exists as to fertilizer's profitability for average smallholder farmers (Duflo, Kremer and Robinson, 2008; Koussoubé and Nauges, 2017) and benefits have been shown to be constrained by vulnerable farmers' ability to access and use complementary inputs (Ricker-Gilbert and Jayne, 2017; Harou et al., 2017). Further, there is some evidence that yield response to fertilizer might be diminished by the more-acidic than average soil in sub-Saharan Africa (Burke, Jayne and Black, 2017). However, in a recent randomized controlled trial, a temporary input subsidy, which provided targeted discount vouchers for a bundle of improved maize and fertilizer to farmers believed to have high potential gains from the program, was found to have lasting effects of increased yields (Carter, Laajaj and Yang, 2021). The mixed evidence in support of the average agricultural and economic benefits of chemical fertilizer comes with longstanding acknowledgment that they may also increase yield variability (Just and Pope, 1979).

The final management practice we study is production diversity. Of the three, the largest literature assessing the relationship between a management practice and nutritional outcomes exists for production diversity. For the most part, dietary diversity is positively associated with on-farm production diversity. The evidence, however, is mixed (Rosenberg et al., 2018; Jones, 2017). In a meta-analysis of 45 studies based in 26 countries, Sibhatu and Qaim (2018*b*) found small but positive effects of production diversity on dietary diversity. There is also evidence that measurement and definitions can drive some of the relationships found between production diversity and nutrition. For example, production diversity is positively associated with dietary indicators but only when considering the number of species produced rather than the number of food groups (Sibhatu and Qaim, 2018*a*). In another study, increased production of non-staple crops drove increasing measures of dietary diversity (Gupta, Sunder and Pingali, 2020).

2 Methodology

In the analysis below, we focus on estimating the association between nutritional outcomes, drought, and management practices. We consider measures of both dietary diversity and food security as nutritional outcomes, drawing particular attention to their imperfect overlap. While we believe the evidence provided to be useful for understanding the relationships between management practices and nutritional outcomes, we refer to our results as associations rather than causal impacts. Though we use the panel nature of the data and natural variation in drought to draw as clean a picture as possible, the scope for selection into the three management practices considered – improved seed use, chemical fertilizer use, and production diversity – makes the exclusion restriction necessary for a causal claim unobtainable. Far from invalidating our analysis, we believe that acknowledging our work as largely descriptive strengthens the core question of the paper as to whether drought erodes the benefits of improved management practices: if drought is still damaging despite selection into management practices then it must be harmful, indeed.

Our analysis proceeds in three steps. We begin by briefly demonstrating the relationship between dietary diversity and food security. Previous literature has raised questions with regard to the use of food security measures and dietary diversity measures as indicators of household nutritional quality (Faber, Schwabe and Drimie, 2009; Carletto, Zezza and Banerjee, 2013; Jones et al., 2013; Barrett, 2010). Our analysis is based on extensive household consumption and risk exposure data. This allows for an informative discussion of the imperfect overlap between food security and dietary diversity and how each is affected by drought.

We then move on to consider whether, on average, management practices are associated with better nutritional outcomes and whether, on average, drought is associated with worse nutritional outcomes. We consider a number of outcome variables for both dietary diversity and food security. Dietary diversity outcomes are counts of either the food categories (household dietary diversity score) or number of food items (food variety score) a household reports consuming during the recall period .

Associations for count variables are estimated using the Poisson quasi-maximum likelihood estimator[2]. Equation 1 below represents the conditional mean estimated to study the associations between the dietary diversity outcomes (y_{it}), management practices (M_{it}^j), and drought (D_{it}). We use two measures of drought, both binary. Here, as below for the food security outcomes, we rely primarily on individual fixed effects (c_i) and a set of controls for time-varying characteristics (X_{it}) to purge as many confounding influences from the associations of interest as possible. For all specifications without individual fixed effects, the set

[2]All specifications use robust standard errors in order to draw appropriate inference even if the variance of the outcome is not equal to the mean, as would be expected for a Poisson-distributed random variable. The Poisson quasi maximum likelihood estimator is consistent so long as $Var(Y|X) = \sigma^2 E[Y|X]$. This is true even in the case of "over dispersion", where $\sigma^2 > 1$.

of controls includes an indicator for economic well-being (simple poverty score), an indicator for off-farm income, distance to the nearest market, and country and year fixed effects. In specifications with individual fixed effects, country and distance to the nearest market are omitted.

$$E[y_{it}|M_{it}, D_{it}, X_{it}, c_i] = c_i \cdot exp\left(\sum_{j=1}^{3} \beta_j M_{it}^j + \theta_1 D_{it} + X'P\right) \tag{1}$$

We then recover and report the semi-elasticities[3] associated with each management practice (Equation 2) and drought (Equation 3).

$$\frac{E(y_{it}|M_{it}^j = 1, M_{it}^{-j}, D_{it}, X_{it}, c_i) - E(y_{it}|M_{it}^j = 0, M_{it}^{-j}, D_{it}, X_{it}, c_i)}{E(y_{it}|M_{it}^j = 0, M_{it}^{-j}, D_{it}, X_{it}, c_i)} = exp(\beta_j) - 1 \tag{2}$$

$$\frac{E(y_{it}|D_{it} = 1, M_{it}, X_{it}, c_i) - E(y_{it}|D_{it} = 0, M_{it}, X_{it}, c_i)}{E(y_{it}|D_{it} = 0, M_{it}, X_{it}, c_i)} = exp(\theta_1) - 1 \tag{3}$$

In addition to the dietary diversity variables, two food security variables are considered – a binary indicator and a continuous version of the Household Food Insecurity Access Scale (HFIAS) capturing the severity of food insecurity (Coates, Swindale and Bilinsky, 2007). Associations for these outcomes are estimated using ordinary least squares [4] (Equation 4).

$$E[y_{it}|M_{it}, D_{it}, X_{it}, c_i] = \sum_{j=1}^{3} \beta_j M_{it}^j + \theta_1 D_{it} + X'P + c_i \tag{4}$$

Finally, we turn to whether the association between management strategies and nutritional outcomes varies with a houseshold's drought experience. In order to see whether differences in nutritional outcomes for households adopting a particular management practice

[3] See Shang, Nesson and Fan (2018) for details on recovering semi-elasticities from binary and interacted coefficients from Poisson regression.

[4] We compare the OLS results for the binary food security measure to Logit results in the Appendix. A fixed effect Logit does not allow for the recovery of marginal effects. In specifications without fixed effects, marginal effects are comparable to the OLS results. We thus focus primarily on the OLS results.

accrue primarily during drought or non-drought years, we estimate Equation 5 for dietary diversity measures and Equation 6 for food security measures.

$$E[y_{it}|M_{it}, D_{it}, X_{it}, c_i] = c_i \cdot exp\left(\sum_{j=1}^{3} \beta_j M_{it}^j + \theta_1 D_{it} + \sum_{j=1}^{3} \gamma_j M_{it}^j \times D_{it} + X'P\right) \quad (5)$$

$$E[y_{it}|M_{it}, D_{it}, X_{it}, c_i] = \sum_{j=1}^{3} \beta_j M_{it}^j + \theta_1 D_{it} + \sum_{j=1}^{3} \gamma_j M_{it}^j \times D_{it} + X'P + c_i \quad (6)$$

From Equation 5 we can recover semi-elasticities describing the association between each management practice and dietary diversity measures without drought (Equation 7) and with drought (Equation 8). Associations between management practices and food security without drought and with drought (β_j and $(\beta_j + \gamma_j)$ respectively) can be recovered from Equation 6.

$$\text{No Drought:} \qquad exp(\beta_j) - 1 \quad (7)$$

$$\text{Drought:} \qquad exp(\beta_j + \gamma_j) - 1 \quad (8)$$

2.1 Data

We make use of panel data collected from a randomly selected sample of around 3,000 maize farmers in Tanzania and Mozambique over the period 2016-2018. While the three year panel is unbalanced, 98.2% of respondents appear in all three waves. The remaining 1.8% appear in the first two waves. The data were collected as part of a USAID-funded study of drought risk and mitigation undertaken by researchers from the BASIS Feed the Future Innovation Lab in collaboration with the International Center for the Improvement of Maize and Wheat (CIMMYT) and local partners.

These data are well matched to the current task as they contain detailed information on households' food consumption, food security status, and agricultural practices. Uniquely,

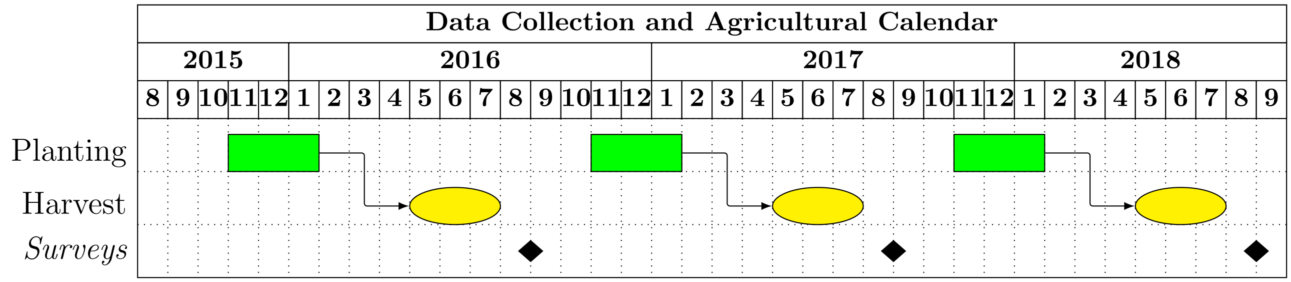

Figure 1: **Timeline of Data Collection.** Planting months are indicated by the green rectangles. The harvest months are indicated by the yellow ovals. Typically, January through March is the most food insecure period, the 'lean season.'

the data also contain household-specific drought experience obtained by matching household locations and maize planting dates to high resolution satellite data on rainfall and vegetative health throughout the maize growing season. Figure 1 provides more information on the timing of the data collection. Data were collected after harvest each season. Dietary diversity measures are a seven day recall at the time of the survey. Food security measures are a recall of the last twelve months– including experiences during the months of January through March when food security is most tenuous for households.

Table 1 summarizes a number of key features of respondent households' nutritional outcomes, agricultural practices, and market access. On average, households manage just under four hectares of land in agricultural production (the 99th percentile of farm size was 24 hectares). This area is divided among a number of crops, with roughly half devoted to maize in both countries (58% in Mozambique, 50% in Tanzania). While maize is the dominant staple crop and plays a significant role in both income and nutrition, households raise a variety of other crops and livestock. The average household in the sample produces between five and six crops and different types of livestock (up to 18 different crops and livestock were observed in the data). This diversity in production can contribute to nutritional outcomes in a number of ways – affecting both income and opportunities for own consumption. While there is some non-food cash crop production among respondents, the majority of agricultural activity focuses on food crops. Appendix Table A.2 provides details on agricultural activity and other measures of production diversity in our sample. About half of respondents use

Figure 2: Study Area in Mozambique and Tanzania

improved maize seed varieties, though use of chemical fertilizers remains low. Households also frequently report off-farm sources of income. Sample households are located reasonably far from major markets, with the average household located 43 kilometers (78 minutes of travel time) away.

Two different remotely sensed data sets are used to generate household-specific drought indicators. First, we use rainfall estimates from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), which are created using remotely sensed cloud cover density and any available on-the-ground station data at a 0.05° resolution (Funk et al., 2015). These data have been shown to have low bias in East Africa and therefore are a good source for assessing the role of drought in agricultural and nutritional outcomes for maize-growing regions (Dinku et al., 2018; Beck et al., 2017). In the region being studied, maize takes between 90-120 days to mature after planting and requires roughly 500 - 800 mm of rainfall (FAO, 2015; Sah et al., 2020). As such, we create a household-level measure of 120-day rainfall accumulation beginning with household-specific maize planting dates and locations. We then create a binary measure of drought that indicates rainfall below 500 mm.

Second, acknowledging that agricultural drought is about more than cumulative rainfall, we use Global Vegetation Health Index (VHI) data published by the NOAA Center for Satellite Applications and Research (STAR). The VHI combines a proxy of soil moisture based on the Normalized Difference Vegetation Index with a proxy for thermal conditions to obtain an index of plant stress. Index values below 40 are associated with loss of crops and pasture production (STAR, 2018). As with rainfall, we create a binary indicator equal to one if the average VHI for a household's location is below 40 over the 120-day period beginning with household-specific planting dates.

Table 2 shows the average drought experience for households across years in the panel. Around half of the individual-year observations are characterized by drought, reinforcing the prevalence of drought as a hazard among this population of maize producers. Importantly, there is substantial individual-level variation in drought experience across the years in the panel. Using VHI, which serves as the primary drought measure in the results below, 71.5% of households experience both a drought and a non-drought year over the period reflected in the data[5].

A similar story exists for the management practices under study. Fifty-two percent of individuals change their use of improved maize across the three years in the panel. For production diversity, primarily measured as the number of crops and livestock species produced, the average difference between the minimum and maximum values reported by a household across the years in the data is four – over a full standard deviation. The least amount of variation is observed in chemical fertilizer use, which is uncommon among the households sampled. Ninety-percent of households never report using chemical fertilizers and only nine percent change their fertilizer use status over the course of the three year panel.

[5] 80.8% of households, using the rainfall measure, experience both drought and non-drought years. See Appendix Figure A.1 for more on the overlap between the two drought measures.

Table 1: Descriptive Statistics by Country

Management Practices	Combined	Mozambique	Tanzania
Production Diversity	5.42	6.32	4.75
(no. crops)	(3.03)	(2.96)	(2.91)
Use Improved Maize	0.51	0.35	0.62
(0/1)	(0.50)	(0.48)	(0.48)
Use Chemical Fert.	0.05	0.04	0.05
(0/1)	(0.21)	(0.20)	(0.22)
Nutritional Outcomes			
Dietary diversity score	8.33	8.16	8.45
(no. of food groups consumed)	(1.95)	(2.07)	(1.84)
Food variety score	9.80	10.63	9.17
(no. of food items consumed)	(6.91)	(5.50)	(7.74)
Food Secure	0.55	0.40	0.66
(0/1)	(0.50)	(0.49)	(0.47)
Severity of Food Insecurity	18.18	24.74	13.28
(HFIAS, continuous)$^{+}$	(28.34)	(32.02)	(24.10)
Household Characteristics			
Farm size	3.87	4.46	3.42
(ha)	(6.54)	(6.95)	(6.19)
Off-farm income source	0.55	0.71	0.42
(0/1)	(0.50)	(0.45)	(0.49)
Simple Poverty Score^{++}	32.91	26.40	37.71
	(14.32)	(12.15)	(13.89)
Distance to a major market	43.24	28.23	54.28
(km)	(32.77)	(25.80)	(32.96)
Observations	9343	3997	5346

Variable means are presented with standard deviations in parentheses below.

+ Higher values are associated with increased food insecurity

++ Higher values are associated with a decreased probability of being below the poverty line

Table 2: Prevalence of Drought by Year

Drought Measure	2016	2017	2018	Full Panel
VHI $< 40^{+}$	0.65	0.51	0.37	0.51
Rainfall < 500 mm^{++}	0.60	0.42	0.32	0.45
Observations	3004	3004	2951	8959

Proportions of households experiencing each type of drought by year and overall.

$^{+}$ Vegetative Health Index (VHI) data obtained from STAR (2018). A VHI below 40 is indicative of plant stress.

++ Constructed using CHIRPS Rainfall data (Funk et al., 2015). Rainfall below 500 mm over its 120 growing season is detrimental to maize (FAO, 2015; Sah et al., 2020).

2.2 Food Security and Dietary Diversity

The center panel of Table 1 contains summaries of the four nutritional outcomes that figure prominently in our analysis. It is widely recognized that consuming a diverse diet is important for health (Ruel, 2003). A variety of approaches exist for measuring diverse diets, however. We study two: a count of the number of food groups consumed by a respondent household during a seven day recall period (dietary diversity score), recommended by the United Nations Food and Agriculture Organization (Kennedy, Ballard and Dop, 2011), and a simple count of food items consumed (food variety score) over the same period, as in Sibhatu, Krishna and Qaim (2015). The average household reports consuming fewer than ten distinct food items from eight of the twelve food groups.

We also consider two different measures of food security. Both are constructed from a set of questions that ask respondents whether they faced food insecurity events (e.g. being forced to reduce the number or variety of meals, going an entire day without eating) over the previous 12 months. The first measure is a binary indicator for food security equal to one if a household was food secure and equal to zero if the household faced any food insecure events. As such, it is a rather blunt measure.

The second measure, the Household Food Insecurity Access Scale (HFIAS) (Coates, Swindale and Bilinsky, 2007), uses the nature and frequency of food insecure events to capture the depth of food insecurity rather than simply its prevalence. Knueppel, Demment and Kaiser (2010) validate the instrument in the Tanzanian context, finding it to have good reliability and to capture both elements of insufficient food quality and insufficient food intake. The HFIAS ranges from zero to 146 with higher values indicating a more severe level of food insecurity. The maximum observed in our sample was 100. This scale can also be translated into a set of discrete categories. For example, a household that reports occasionally having to resort to less-preferred foods but suffered no other food insecure events is categorized as mildly food insecure. On the other hand, a household that reports that some family members have had to go an entire day and night without eating is classified as severely food insecure.

Food insecurity is common and severe in the set of households represented by the data. Thirty-one percent of households are labeled severely food insecure by the discrete version of the HFIAS and an additional 14% are labeled as moderately or mildly food insecure. Only 55% of observations come from food secure households.

While both food security and dietary diversity measures are intended to shed light on a household's nutritional security, there are a variety of reasons to suspect that the they might capture different aspects of a household's food access experience. Notably, it is possible for households to maintain adequate access to a quantity of food that makes them appear food secure but be unable to access the diversity of food necessary for a nutritious diet.

To see the extent to which dietary diversity and food security overlap, Table 3 presents a tabulation of households according to their food security status and dietary diversity. Following Swindale and Bilinsky (2006), the rows of the table separate households consuming more and fewer than ten food groups, which corresponds to the 75th percentile of the dietary diversity score. This simple exercise highlights both substantial overlap and significant differences. In the majority of cases – 56% of household-year observations – food secure households exhibit high dietary diversity and food insecure households exhibit low dietary diversity. At the same time, 34% of food secure households exhibit low dietary diversity. The opposite is less common, with only 10% of observations classified as food insecure but high dietary diversity. This is consistent with the idea that households may use a variety of strategies to protect their food security status that might require sacrificing dietary diversity and, thus, nutritional quality.

Table 3: Overlap Between Food Security and Dietary Diversity by Household-Year Observation

	Food Insecure	Food Secure	Total
Low Dietary Diversity	3,093	3,004	6,097
High^{+} Dietary Diversity	911	1,932	2,843
Total	4,004	4,936	8,940

+High Dietary Diversity defined as a score $\geq$ 10, which corresponds with the 75th percentile of dietary diversity scores in this sample per the recommendation of Swindale and Bilinsky (2006)

Figure A.2 in the Appendix takes the comparison a step further, plotting the mean dietary diversity score for households in each category of the HFIAS. On average, lower dietary diversity is observed among households categorized as moderately and severely food insecure but not for mildly food insecure households.

3 Analysis

3.1 Nutritional Outcomes and Drought

We begin our analysis by documenting the association between drought and nutritional outcomes. As discussed in Section 1.1, there is ample evidence that drought can be damaging to household well-being. Nor is drought infrequent. Table 2 noted that nearly half of the observations in the data come from households that recently experienced drought conditions during the growing season for maize. This statistic is made visible in Figure 3, which displays households' drought experience across the three years represented in the data.

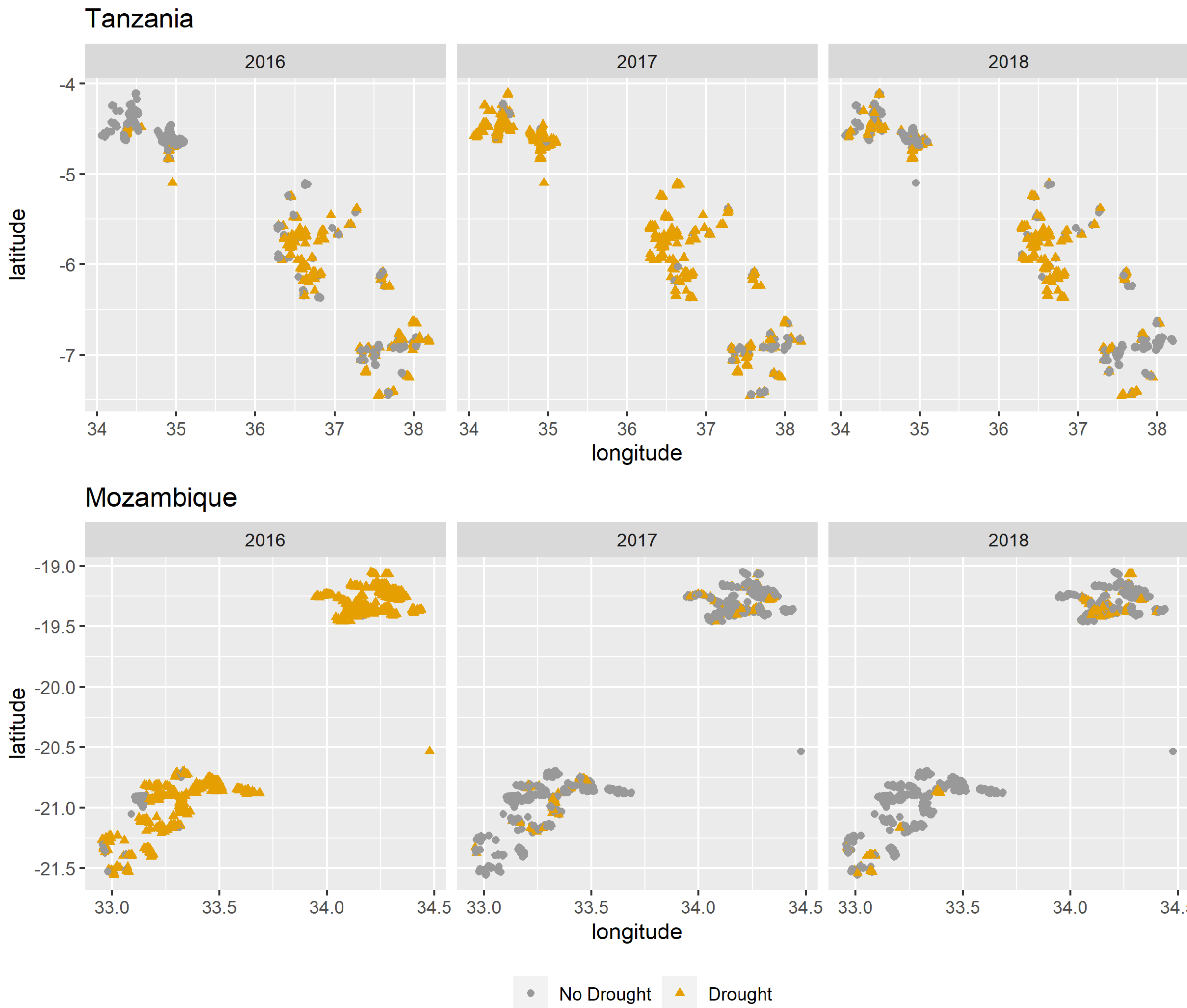

Figure 3: **Plot of Sample Household Coordinates by Drought Outcomes.** Drought is indicated if the Vegetative Health Index falls below 40.

The frequent occurrence of drought is already reflected, if obscured by aggregation, in the dietary diversity and food security statistics reported in Table 1. Here we formalize that relationship by estimating the association between drought and our various nutritional outcomes as described by Equations 1 and 4. Figure 4 contains the resulting estimates, reported as percentage point changes for the food security binary measure and semi-elasticities for dietary diversity score. Across specifications, both rainfall-measured drought and drought defined using the VHI consistently show the adverse relationship between drought and nutritional outcomes. In our preferred fixed effects specification, VHI-indicated drought is associated with a decrease of 5.77 percentage points in the probability of being food secure. That is a decrease of 10.5% relative to the mean as shown in Table 1. In Appendix Table A.4, we show that drought is also associated with an increase in the severity of food insecurity. In addition, drought is associated with a decrease in the dietary diversity score of 9.33%, roughly 0.8 food categories evaluated at the mean. Similar estimates, shown in Table A.5, are obtained using the rainfall drought measure.

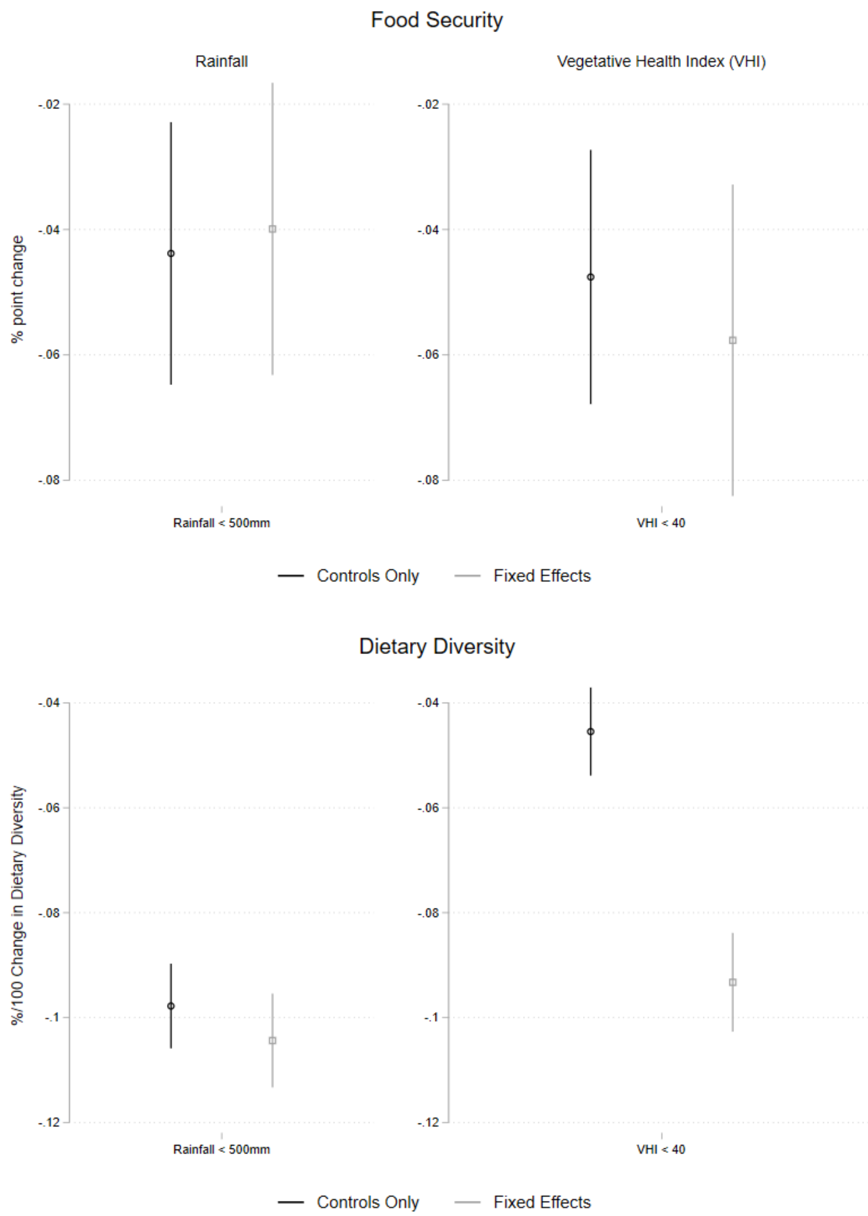
Food Security
Rainfall
Vegetative Health Index (VHI)
% point change
-.02
-.04
-.06
-.08
Rainfall < 500mm
VHI < 40
Controls Only
Fixed Effects
Dietary Diversity
%/100 Change in Dietary Diversity
-.04
-.06
-.08
-.1
-.12
Rainfall < 500mm
VHI < 40
Controls Only
Fixed Effects

Figure 4

The clear decrease in nutritional measures associated with drought has both short and long-term implications for household well-being as well as for policy makers. Drought drives up the need for immediate, in-kind assistance, which is costly for governments to provide. In-kind assistance, however, is also slow while hunger is immediate. Households cannot wait around for assistance, particularly those with children for which malnutrition carries risk of lasting damage to physical and cognitive development (Alderman, Hoddinott and Kinsey, 2006; Hoddinott and Kinsey, 2001). Janzen and Carter (2019) estimate that poorer households respond to this challenge by reducing consumption – as in Figure 4 – while wealthier households sell assets to afford the consumption they require. While this latter strategy might keep the effects we estimate from being even larger, it also reduces the security of households with respect to future shocks and limits their ability to further their economic position (Carter and Lybbert, 2012; Zimmerman and Carter, 2003).

3.2 Nutritional Outcomes and Management Practices

The previous section demonstrated that drought was negatively associated with both food security and dietary diversity. In this section, we look at the association between the nutritional outcomes and management practices.

We focus on three management practices commonly promoted as beneficial for improving smallholder farm household income, nutrition, and resilience (Ariga et al., 2019; Sasson, 2012; Shiferaw et al., 2014*a*): use of improved seed varieties, use of chemical fertilizers, and production diversity. Our primary definition of production diversity is a count variable of the number of crop and livestock species produced by a household. Alternative measures of production diversity – including the number of food crops and cash crops, number of staple and non-staple crops, and a Margalef index[6] – are presented in the Appendix.

[6] Margalef diversity indices are commonly used in the ecological literature to measure biodiversity and have appeared in the agricultural economics literature as well (Sibhatu, Krishna and Qaim, 2015; Di Falco and Chavas, 2009). We construct our index following Iglesias-Rios and Mazzoni (2014) and others in the ecological literature as $\frac{ln(\#\text{ crops } + \#\text{ livestock species}-1)}{ln(\text{total area in meters squared}}$

Figure 5 summarizes the associations estimated using the fixed effects specifications in Equations 1 (dietary diversity) and 4 (food security). Note that the coefficient estimates for production diversity are those associated with a one standard deviation change (3.03 units) in the number of crop/livestock species produced, while the coefficients on improved maize and fertilizer use correspond to indicator variables. The reported semi-elasticities on the dietary diversity outcomes are obtained via Equation 2. Full results are available in Appendix Table A.4.

Whereas drought had a sizable negative association to nutritional outcomes, both improved maize use and production diversity show favorable associations with dietary diversity, the probability of being food secure, and the depth of food insecurity. Using improved maize is associated with a 4.78% increase in dietary diversity (0.40 food groups) and a 7.02 percentage point increase in the probability of being food secure. A standard deviation increase in production diversity is associated with a 8.44% increase (0.70 food groups) in dietary diversity and a 5.39 percentage point increase in the probability of being food secure. The association we estimate between production diversity and dietary diversity is notably larger than the average reported in the meta-analysis of Sibhatu and Qaim (2018*b*), which found that an additional 16 crop and livestock species would be needed to increase dietary diversity by one food group. In our analysis, an increase of 4.33 species (1.43 standard deviations) would be necessary. The results are more mixed for chemical fertilizer use, which has smaller and statistically insignificant associations with all outcomes.

The results in Figure 5 are encouraging but they tell us little about how these relationships persist in periods when households are at their most vulnerable. As average associations, they necessarily pool and weight the relationship between management practices and outcomes over drought and non-drought years. While improved nutritional outcomes is worthwhile and beneficial at all times, better outcomes in drought years is of particular interest.

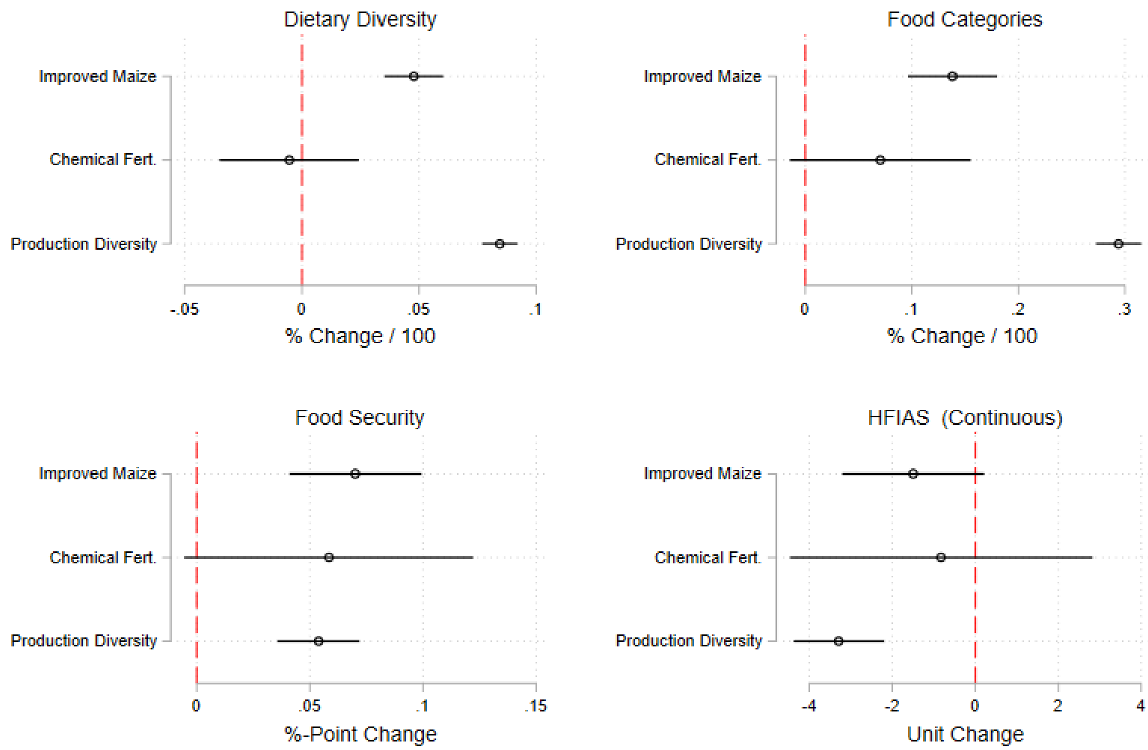

Figure 5: **Coefficient Plot of Management Practices on Nutritional Outcomes.** Note: Improved Maize and Chemical Fertilizer are binary indicators of use. The reported coefficient for Production Diversity is associated with a standard deviation change in the number of crop/livestock species produced. The HFIAS is a measure of insecurity: therefore, negative coefficients represent an improvement in household welfare.

3.3 Does drought "dry up" the benefits of management practices?

We now investigate whether the positive association between management practices and nutritional outcomes persists or erodes in the presence of drought. As shown in Equations 5 and 6, we do this by adding interactions between drought and each management practice. We then recover and compare the association between management practices and nutritional outcomes with and without drought[7]. For dietary diversity outcomes, this is done as shown in Equations 7 and 8. For food security outcomes, we use the relevant β_j and γ_j coefficients from Equation 6. As above, we report results for drought defined both using VHI (Table 4) and rainfall (Table 5).

The first result of note is that use of improved maize varieties and production diversity maintain their favorable associations with dietary diversity and food security outcomes in both drought and non-drought years. This is true using either VHI or rainfall to define drought. Drought, it appears, does not completely dry up the benefits of these management practices.

Similarly, in both the VHI and rainfall tables, the favorable association between improved maize use and nutritional outcomes seems to be driven by drought years. The result is particularly strong for food security outcomes, where there is no statistically significant association in non-drought years but the association in drought years is large in magnitude and highly statistically significant.

There is more variation in the pattern of associations estimated for production diversity, though it remains robustly associated with beneficial nutritional outcomes. Using the VHI measurement of drought, the association between production diversity and both nutritional outcomes are largely similar in drought and non-drought years. Using the rainfall version of drought, associations to dietary diversity hold steady and associations to food security outcomes concentrate more heavily in non-drought years. These slight differences may be driven by the sensitivity of the two drought measures. While they agree in the majority

[7] Stata's *nlcom* routine is used to obtain the coefficients and standard errors reported in Tables 4 and 5

of cases – 71% of the time, per Figure A.1 – VHI is more sensitive and identifies plant stress earlier than the rainfall-alone measure. In years characterized by drought according to the VHI measure, average rainfall was 477 millimeters. Average rainfall in drought years characterized solely by rainfall was 360 millimeters, 25% lower than under the VHI measure.

Table 4: Management Practices, Nutritional Outcomes With and Without Drought (Vegetative Health Index)

	(1)	(2)	(3)	(4)
Outcome	Dietary Diversity	Food Items	Food Secure	HFIAS Continuous
Coefficient Interpretation	Semi-elasticity^{+}		% Point	Unit
		Drought		
VHI < 40	-0.116***	-0.505***	-0.104***	4.388*
	(0.0109)	(0.0208)	(0.0294)	(1.774)
		Management Practices		
Improved Maize				
No Drought	0.0446***	0.109***	0.0180	1.800
	(0.00858)	(0.0269)	(0.0195)	(1.164)
Drought	0.0517***	0.173***	0.120***	-4.615***
	(0.00804)	(0.0288)	(0.0188)	(1.090)
Chemical Fertilizer				
No Drought	-0.0101	0.0286	0.0252	3.279
	(0.0225)	(0.0578)	(0.0453)	(2.807)
Drought	-0.00742	0.0474	0.0617	-2.593
	(0.0187)	(0.0545)	(0.0418)	(2.274)
Production Diversity				
No Drought	0.0794***	0.245***	0.0548***	-3.668***
	(0.00439)	(0.0133)	(0.0108)	(0.624)
Drought	0.0911***	0.353***	0.0524***	-2.787***
	(0.00494)	(0.0146)	(0.0117)	(0.727)
Controls	Yes	Yes	Yes	Yes
Fixed Effects	Year, Indiv.	Year, Indiv.	Year, Indiv.	Year, Indiv.
Observations	8328	8328	8417	8417

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Robust standard errors reported along with coefficients.

Control set: Simple poverty score, indicator for off-farm income, distance to nearest market

Improved Maize and Chemical Fert are binary indicators of use. The reported coefficient for Production Diversity is associated with a standard deviation change.

+ Reported semi-elasticity without drought are $exp(\beta) - 1$ while effects under drought are calculated as $exp(\beta + \gamma) - 1$ where β is the coefficient on the management practice and γ is the coefficient on the relevant interaction term. See Shang, Nesson and Fan (2018) for more details.

Table 5: Management Practices, Nutritional Outcomes With and Without Drought (Rainfall)

	(1)	(2)	(3)	(4)
Outcome	Dietary Diversity	Food Items	Food Secure	HFIAS Continuous
Coefficient Interpretation	Semi-elasticity+		% Point	Unit
		Drought		
Rainfall < 500mm	-0.129***	-0.524***	-0.000452	0.597
	(0.0104)	(0.0193)	(0.0282)	(1.715)
		Management Practices		
Improved Maize				
No Drought	0.0307***	0.0663**	0.0337	0.589
	(0.00746)	(0.0235)	(0.0179)	(1.053)
Drought	0.0844***	0.344***	0.125***	-4.415***
	(0.00945)	(0.0369)	(0.0206)	(1.215)
Chemical Fertilizer				
No Drought	0.00770	0.195***	0.00828	4.704*
	(0.0182)	(0.0535)	(0.0387)	(2.149)
Drought	-0.0375	-0.135**	0.0895*	-5.189*
	(0.0193)	(0.0480)	(0.0433)	(2.425)
Production Diversity				
No Drought	0.0802***	0.261***	0.0723***	-4.229***
	(0.00397)	(0.0123)	(0.0101)	(0.590)
Drought	0.0816***	0.308***	0.0218	-1.663*
	(0.00556)	(0.0155)	(0.0126)	(0.787)
Controls	Yes	Yes	Yes	Yes
Fixed Effects	Year, Indiv.	Year, Indiv.	Year, Indiv.	Year, Indiv.
Observations	8329	8329	8418	8418

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Robust standard errors reported along with coefficients.

Control set: Simple poverty score, indicator for off-farm income, distance to nearest market

Improved Maize and Chemical Fert are binary indicators of use. The reported coefficient for Production Diversity is associated with a standard deviation change.

\+ Reported semi-elasticity without drought are $exp(\beta) - 1$ while effects under drought are calculated as $exp(\beta + \gamma) - 1$ where β is the coefficient on the management practice and γ is the coefficient on the relevant interaction term. See Shang, Nesson and Fan (2018) for more details.

4 Policy Implications and Conclusions

Previous literature, including work published in this journal such as Amadu, McNamara and Miller (2020) and Shiferaw et al. (2014*b*), has demonstrated that certain management practices are associated with improved nutritional outcomes on average. Our analysis further bolsters the evidence supporting policies that promote agricultural inputs and education. We demonstrate that use of improved maize and a diverse portfolio of production are associated with improved nutritional outcomes. Given the different aspects of nutritional quality captured by dietary diversity and food security measures, it is perhaps not surprising that we find some management practices to have a stronger association with food security while others have stronger associations to dietary diversity. Specifically, management practices related to improved inputs in maize production are more closely linked to food security while diversity of production is more strongly linked to dietary diversity.

Policy makers who have focused on the promotion of management practices as a strategy for increasing resilience will likely consider our results to be favorable. With respect to agricultural policy, as noted in Section 1.1, many countries in the region are devoting significant portions of their national budgets to promoting agricultural inputs. A further encouraging result to these parties may be found in the fact that drought – a principal hazard for many households engaged in agriculture – does not erase the benefits of the management practices studied. In fact, the favorable association between improved maize use and nutritional outcomes seems to be strongest during drought years. These results, however, come with a strong word of caution: while the association between management practices and nutritional outcomes was favorable, the level-effects of drought were large and negative.

To demonstrate this point, we use the estimation results from Equations 5 and 6 to project the expected levels of nutritional outcomes for a representative household adopting different management practices under drought and non-drought conditions. We create an "average household"[8] for this exercise and use the average outcome in lieu of a constant

[8]The average household has a simple poverty score of 26.4, has an off-farm income indicator equal to one,

given that the coefficient estimates come from a fixed effect specification.

For dietary diversity, the expected outcome Y for a representative household employing only management strategy j and facing drought conditions D can be obtained by evaluating Equation 9 using the estimated parameters from Equation 5:

$$E[Y|M^j = 1, D, \bar{X}] = exp(\alpha + \hat{\theta}_1 D_{it} + \hat{\beta}_j + \hat{\gamma}_j D_{it} + \bar{X}'\hat{P}) \tag{9}$$

Similarly, without management practice j:

$$E[Y|M^j = 0, D, \bar{X}] = exp(\alpha + \hat{\theta}_1 D_{it} + \bar{X}'\hat{P}) \tag{10}$$

The same approach, though this time with a linear projection, can be used to recover the expected probability of being food secure. Figure 6 contains the results of this exercise for dietary diversity and food security.

Despite being based on results using the VHI definition of drought, where favorable associations erode the least, nutritional outcomes degrade significantly in the presence of drought even for those households adopting better management practices. Generally, they fall below the "no drought" level projected for non-users. In short, the management practices studied seem to represent incomplete adaptation strategies when it comes to fostering nutritional resilience, at least when considered one-by-one.

That management practices represent incomplete adaptation strategies has a number of implications for policy makers and future research. First, while policies promoting management practices may positively influence nutritional outcomes on average, households' nutritional security may remain at risk during disaster events. Put another way, the primary effects of these policies might accrue at precisely the wrong time. A consequence of which is that organizations may continue to reserve significant resources for traditional disaster response programs even as adoption of best management practices expands. This is partic-

and resides in Tanzania.

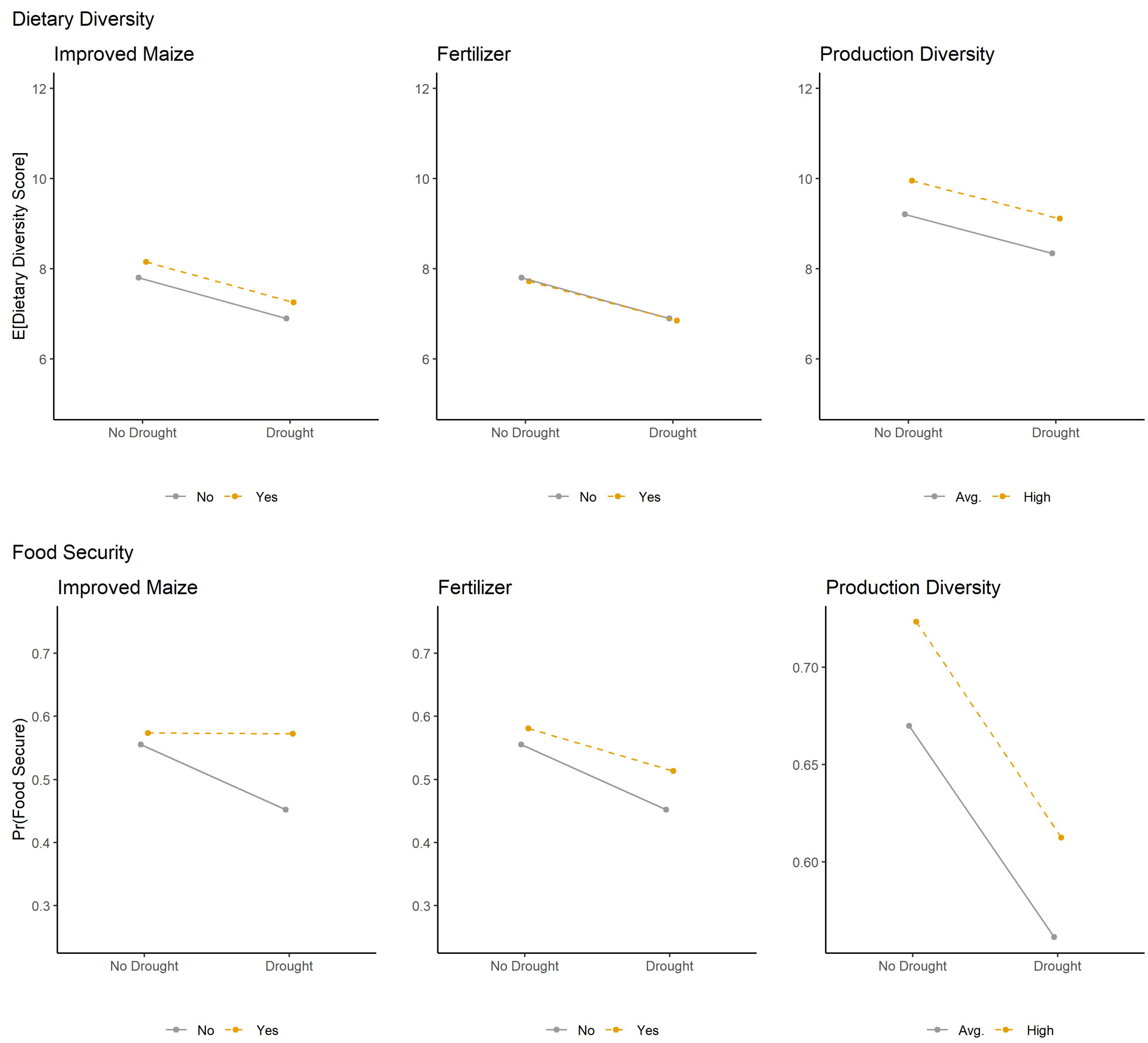

Figure 6: Projected Nutritional Outcome Levels Under Drought and Non-Drought Conditions by Management Practice.

ularly true in the context of climate change and increasingly severe and frequent drought in sub-Saharan Africa. As such, research into risk mitigation – particularly automatic transfer programs and insurance products that kick in as other strategies weaken – may remain an important and open avenue for improving nutritional outcomes for vulnerable households across all states-of-the-world.

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A Additional Tables and Figures

Table A.1: Management Practices and Household Characteristics

	Respondents %	SPS Score^{+} Mean (SD)	Dist. to Market (km) Mean (SD)	Off-Farm Inc. %
Improved Maize				
Use	51	35.0 (14.6)	44.5 (31.2)	56
Do Not	49	29.8 (13.6)	41.4 (33.8)	51.2
Chemical Fertilizer				
Use	5	36.0 (14.4)	31.8 (30.9)	46.9
Do Not	95	32.3 (14.3)	43.5 (32.5)	53.9
Production Diversity^{++}				
Above Average	50	31.3 (13.8)	37.9 (30.3)	66.1
Below Average	50	34.4 (14.6)	47.9 (34.1)	44.3

+ Higher values are associated with a decreased probability of being below the poverty line

++ Production diversity here refers to the number of crop and livestock species produced.

Table A.2: Summary of Agricultural Production Diversity

Panel A: Various Measures of Production Diversity by Country			
	Combined	Mozambique	Tanzania
Production Diversity	5.42	6.32	4.75
(no. crops produced)	(3.03)	(2.96)	(2.91)
Margalef species richness index*	0.46	0.54	0.39
	(0.26)	(0.24)	(0.27)
Food crop production	4.18	4.62	3.85
(no. crops)	(2.21)	(2.14)	(2.21)
Cash crop production	0.71	0.89	0.57
(no. crops)	(0.81)	(0.85)	(0.75)
Staple food crop production	1.40	2.05	0.92
(no. crops)	(1.38)	(1.43)	(1.11)
Non-staple food crop production	2.78	2.57	2.93
(no. crops)	(1.50)	(1.20)	(1.68)
Observations	9343	3997	5346

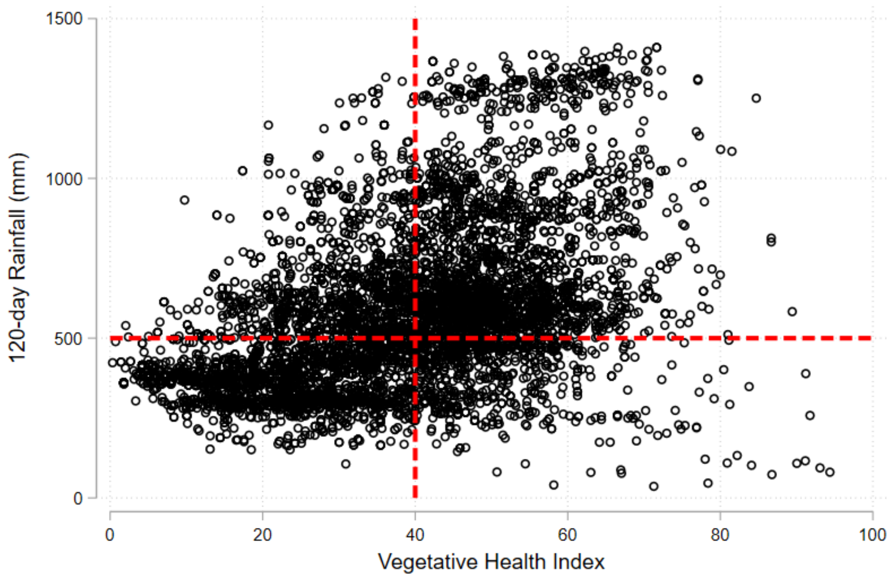
Note: Table reports means (standard deviations)

* A measure of biodiversity, constructed here as $\frac{ln(\#\text{ crops} + \#\text{ livestock species}-1)}{ln(\text{total area in meters squared}}$

Panel B: Production Diversity - Most Commonly Grown Crops					
Staple Crops		Cash Crops		Other Crops	
Maize	99%	Sesame	25%	Bananas	28%
Sorghum	41%	Sunflower	25%	Citrus Fruits	24%
Cassava	37%	Cashew	19%	Horticulture Crops	20%
Sweet Potato	35%	Groundnuts	10%	Mangoes	5%

Percentage of household reporting production of each crop across all three years

Figure A.1: Drought Measured Using Rainfall and Vegetative Health Index



Overlap Between VHI- and Rainfall-Measured Drought

	VHI > 40 (No Drought)	VHI < 40 (Drought)	Total
Rainfall > 500 (No Drought)	3,262	1,611	4,873
Rainfall < 500 (Drought)	857	2,748	3,605
Total	4,119	4,359	8,478

Vegatative Health Index (VHI) from NOAA STAR project (STAR, 2018)

CHRIPS Rainfall data (Funk et al., 2015)

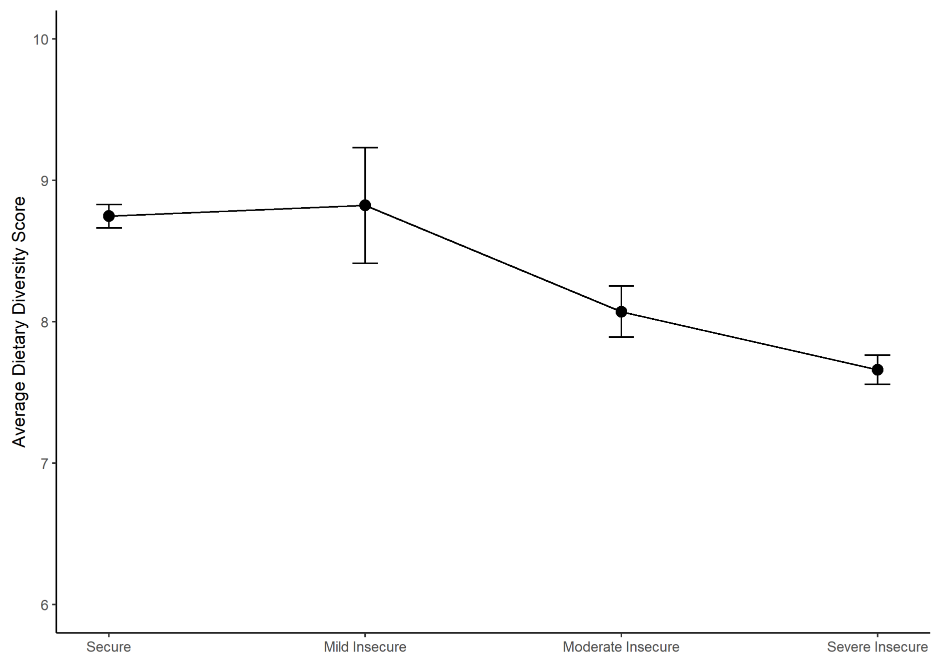


Figure A.2: **Plot of Average Dietary Diversity Score Across Food Security Categories.** Severely food insecure households, on average, consume diets with 7.66 food categories compared to the 8.75 categories consumed by food secure households – a statistically significant 1.09 (12.5%) fewer food groups. The difference between food secure and mildly food insecure households, on the other hand, is near zero and statistically insignificant.

Table A.3: Drought and Food Security (LPM vs Logit Marginal Effects)

	Linear Probability Model		Logit (Marginal Effects)	
	(1)	(2)	(3)	(4)
Ranfall < 500 mm	-0.0438***		-0.0426***	
	(0.0107)		(0.0104)	
VHI < 40		-0.0476***		-0.0467***
		(0.0103)		(0.0103)
Controls	Yes	Yes	Yes	Yes
Fixed Effects	Year, Country	Year, Country	None	Year, Country
Observations	8418	8417	8418	8417

Control set: Simple poverty score, indicator for off-farm income, distance to nearest market
Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.4: Associations Between Nutritional Outcomes, Management Practices and Drought (Vegetative Health Index)

	(1)	(2)	(3)	(4)
Outcome	Dietary Diveristy*	Food Items*	Food Secure	HFIAS Continuous
Coefficient Interpretation	Semi-elasticity^{+}		% Point	Unit
	Drought			
VHI < 40	-0.0933***	-0.363***	-0.0577***	2.746***
	(0.00480)	(0.0102)	(0.0127)	(0.745)
	Management Practices			
Improved Maize	0.0478***	0.138***	0.0702***	-1.494
	(0.00642)	(0.0214)	(0.0149)	(0.871)
Chemical Fert.	-0.00540	0.0703	0.0585	-0.820
	(0.0152)	(0.0432)	(0.0325)	(1.860)
Production Diversity	0.0844***	0.294***	0.0539***	-3.286***
	(0.00386)	(0.0109)	(0.00925)	(0.557)
Controls	Yes	Yes	Yes	Yes
Fixed Effects	Year, Indiv.	Year, Indiv.	Year, Indiv.	Year, Indiv.
Observations	8328	8328	8417	8417

Standard errors in parentheses

Robust standard errors reported along with coefficients. *Reported estimates are recovered semi-elasticities.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.5: Associations Between Nutritional Outcomes, Management Practices and Drought (Rainfall)

	(1)	(2)	(3)	(4)
Outcome	Dietary Diveristy*	Food Items*	Food Secure	HFIAS Continuous
Coefficient Interpretation	Semi-elasticity^{+}		% Point	Unit
		Drought		
Rainfall $<$ 500mm	-0.104***	-0.419***	-0.0399***	2.150**
	(0.00456)	(0.00899)	(0.0119)	(0.695)
		Management Practices		
Improved Maize	0.0514***	0.160***	0.0739***	-1.649
	(0.00632)	(0.0213)	(0.0149)	(0.869)
Chemical Fert.	-0.0112	0.0513	0.0506	-0.487
	(0.0147)	(0.0381)	(0.0324)	(1.848)
Production Diversity	0.0816***	0.281***	0.0559***	-3.346***
	(0.00379)	(0.0108)	(0.00926)	(0.556)
Controls	Yes	Yes	Yes	Yes
Fixed Effects	Year, Indiv.	Year, Indiv.	Year, Indiv.	Year, Indiv.
Observations	8329	8329	8418	8418

Standard errors in parentheses

Robust standard errors reported along with coefficients. *Reported estimates are recovered semi-elasticities.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

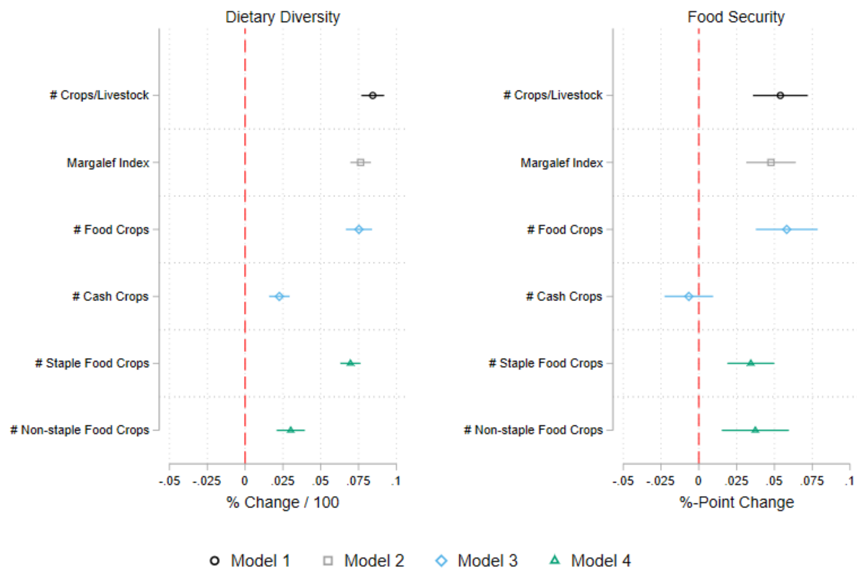


Figure A.3: Nutritional Outcomes and Alternative Measures of Production Diversity

Note: The reported coefficient for each measure is associated with a standard deviation change in the number of crops produced/index.

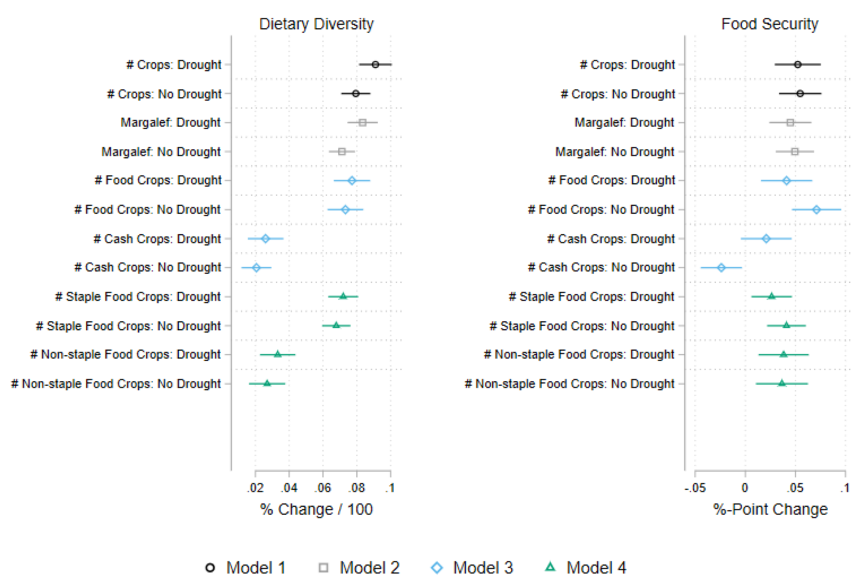


Figure A.4: Nutritional Outcomes, Drought (VHI), and Alternative Measures of Production Diversity

Note: The reported coefficient for each measure is associated with a standard deviation change in the number of crops produced/index.