AGRICULTURAL DRIVERS OF CHILDREN'S NUTRITION AND FOOD SECURITY IN MVOMERO, TANZANIA

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Abstract

The main research question assessed in this paper is: What land use and agricultural practices most significantly influence nutritional and food security outcomes? In particular, are there specific crop growing or selling or irrigation practices that, when performed by a household, help to reduce the risk that children under five years old in that household are stunted or anemic or help to increase perceived food security by the household head? I use data collected in 2011 and 2013 in the Mvomero district of Tanzania in order to answer these questions. Using a combination of data at the household level on land use practices and on the individual level for health measures, I perform logit and linear regression analysis to identify any consistent significant associations between the two groups. My results are varied: some agricultural practices are associated with stunting or anemia, while others are more strongly associated with measures of food security. The number of children in a household is negatively associated with both food security measures, implying that larger households in the region have difficulty keeping up with food demands. My findings point to the fact that there is no silver bullet in the quest to improve childhood nutrition and food security in Mvomero, Tanzania and worldwide.

Introduction

The Universal Declaration of Human Rights states, "Everyone has the right to a standard of living adequate for the health and well-being of himself and his family, including food," (United Nations General Assembly, 1948). While significant progress has been made in reducing hunger worldwide, the latest Food and Agriculture Organization statistic estimates 793 million people were undernourished in 2014 (FAO, 2015). The continued presence of hunger worldwide prompted its inclusion in the recent Sustainable Development Goals, which include a goal to, "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture." Specifically, the goal calls for a complete end to hunger and malnutrition by 2030 (UN, 2015). Progress towards these goals has been immense over the past few decades. The number of people living in hunger has fallen by 216 million since 1990, and by 167 million in the past ten years alone. This is a decrease since 1990 from 22.3% of the global population to 12.9% (FAO, 2015). Figures 1 and 2 provide visual representations of recent global and regional trends in undernourishment, which is defined as the inability of an inability to acquire food to meet daily caloric needs over the course of a year (FAO, 2016).

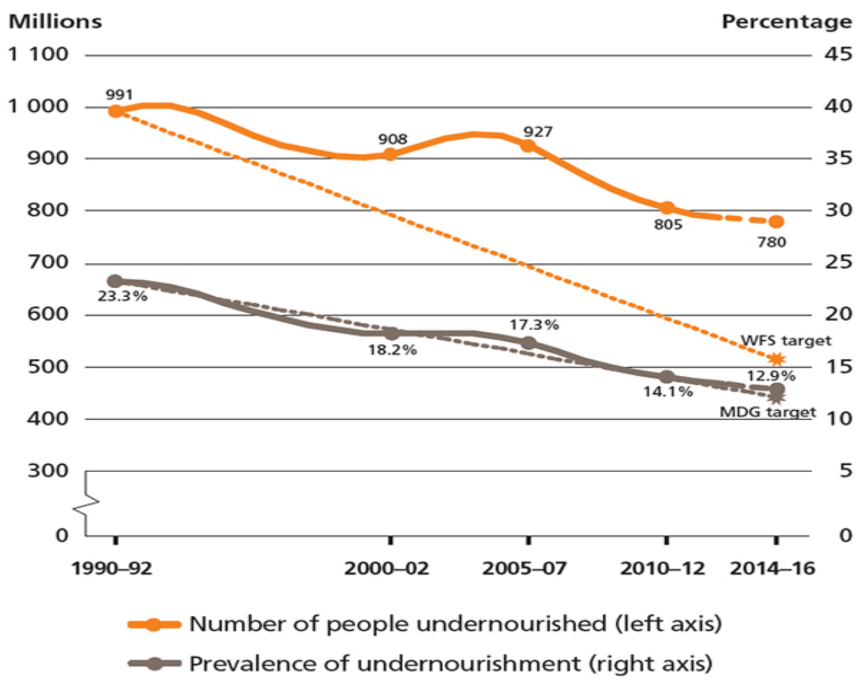


Figure 1: Undernourishment globally between 1990 and 2016 (FAO, 2016).

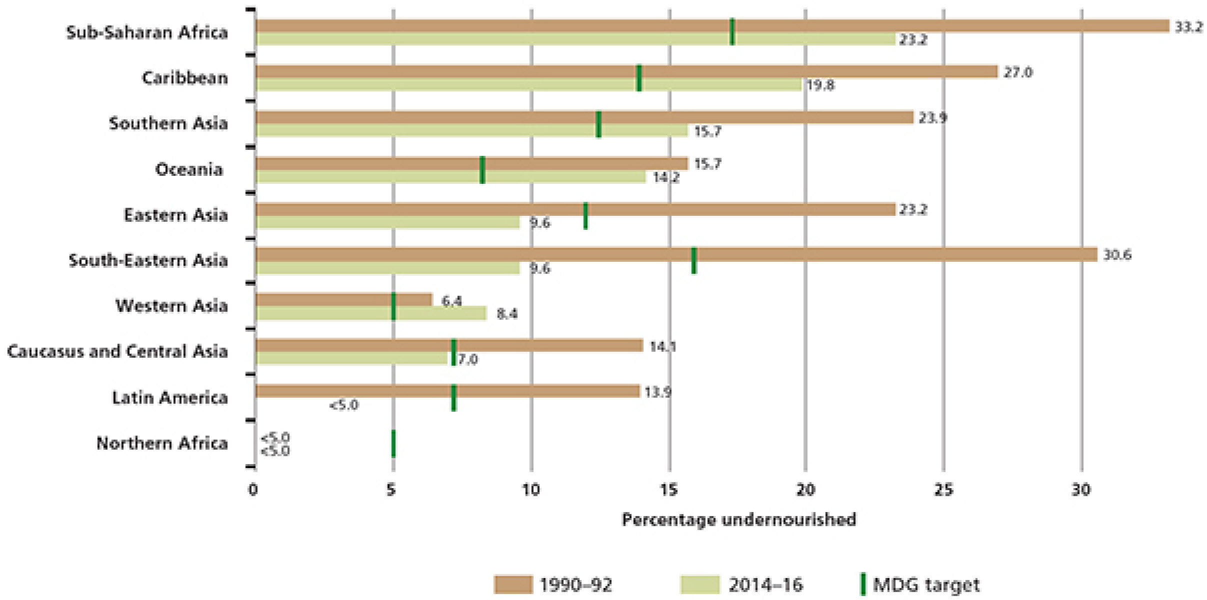


Figure 2: Undernourishment by region in 1990-92 compared with 2014-15 (FAO, 2016).

While such improvements are notable, they do not paint a full picture of how trends in hunger have changed regionally. East Africa in particular has suffered from slower improvement in nutritional outcomes than other areas. Hunger and undernutrition can be measured in several ways. For the purpose of this paper, I look at two nutritional outcomes in children: stunting and anemia. Stunting is a ratio of height-for-age, and is defined by the World Health Organization as a ratio two or more standard deviations or Z-scores below the reference population's median. Anemia refers to insufficient red blood cells or low oxygen-carrying capacity of red blood cells. WHO defines moderate and severe anemia relative to established cut-off points. In children age 6 to 59 months, a hemoglobin level between 70 and 99 is considered "moderate" anemia and a hemoglobin level lower than 70 constitutes "severe" anemia (WHO, 2016).

Ethiopia, the Democratic Republic of the Congo, and Tanzania have the highest childhood stunting rates on the African continent. Rates of childhood stunting have decreased by over seven percentage points since 2010, but still remain high at about 37% (Global Nutrition Report, 2014). Rates of stunting and underweight in Tanzanian children may be as high as 52.5% and 43% respectively, with significantly more stunted and underweight boys than girls (Lwambo et al., 2000). Stunting reduction rates differ greatly between countries (Restrepo-Méndez et al., 2015). Figure 3 shows trends in stunting by continent.

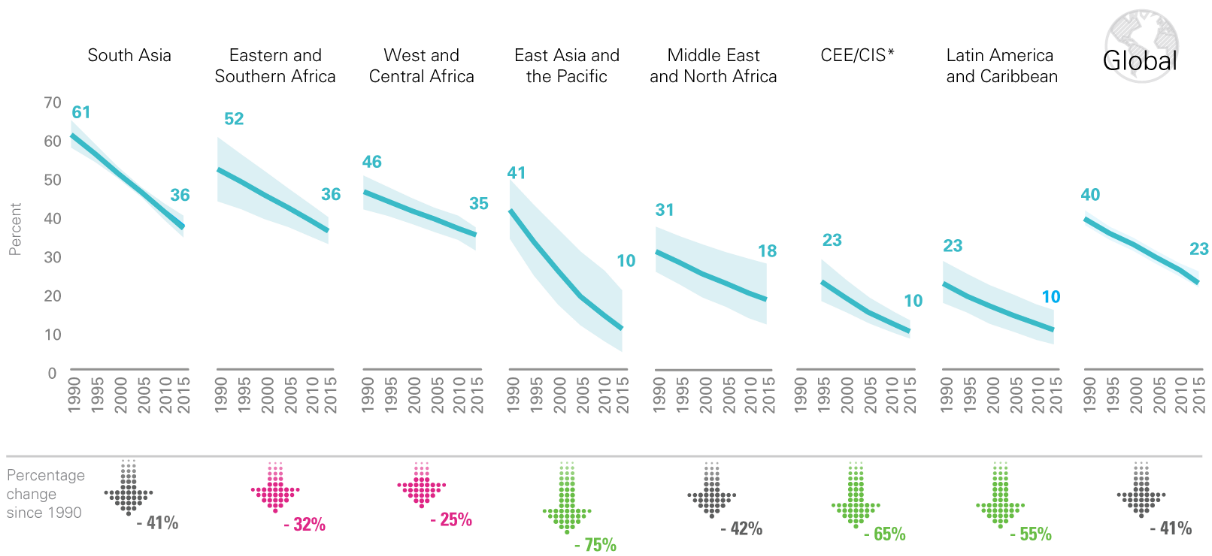


Figure 3: Changes in stunting between 1990 and 2015 broken down by region (UNICEF, 2016).

Consequences of Nutritional Deficiencies

Nutritional deficiencies and subsequent incidence of stunting and anemia, have consequences for individuals, their families, and their entire communities. In particular, these consequences can appear as higher mortality rates, lower quality of life and education rates, and worse economic outcomes.

Mortality

It is difficult to assess the role of undernutrition in mortality because of its complicated relationship to other conditions and diseases. An estimated 50% of child deaths in low-income countries can be linked to undernutrition (Heikens et al., 2008). Of that 50%, most (about 83%) can be attributed to moderate, rather than severe, levels of malnutrition (Pelletier et al., 1995). Both stunting and wasting have been shown to increase the likelihood of childhood mortality through decreased body fat and the fat-regulating hormone leptin (Briend et al., 2015), and the coincidence of the two in many populations from nutritional deficiencies increases that likelihood of mortality further. In addition, anemia has been shown to be linked to infant and childhood mortality. Iron-deficiency-related anemia has been linked to death in children under the age of five in about 6% of cases (Brabin et al., 2001), while the mortality rate associated with all types of anemia, including malarial related, has been shown to be between 8 and 17% in Malawi (Calis et al., 2008).

Economic Outcomes

Studies have shown an estimated 11% increase in average national incomes associated with a one-fifth reduction in the rate of stunting. For Tanzania in particular, research has estimated a 15.9 benefit-cost ratio of investing in stunting reduction ((Hoddinott et al., 2013). The relationship between nutritional deficiency and economic outcomes is usually explained by education. Because improper nutrition in children under the age of five has been linked to slow neurological development, children exhibiting consequences such as stunting, wasting, and anemia typically do not perform well in school (Roncagliolo et al., 1998; Bobonis et al., 2006). Alderman et al. (2006) found that an increase in childhood height from the median in rural Zimbabwe to the median in the developed world would increase the highest level of education achieved on average by 0.85 grade levels. They also found that this increase in height would be associated with beginning school six months earlier relative to the rural Zimbabwe average.

Nutrition and the Environment

Drought incidence is expected to increase in Tanzania due to the changing climate (Paavola, 2008). Because of the high reliance on rain-fed agricultural methods (as opposed to irrigated agriculture), Tanzania's agriculture is particularly vulnerable to decreased rain amounts. Arndt et al. (2012) compare agricultural production in several climate scenarios, including a baseline scenario of no climate change. In all models, they find that the rate of increase in agricultural production slows as a result of climate change. Even with a wide variance in outcomes based on different climate projects, they find that crop productivity will not be able to keep up with population growth. This is particularly important in a country like Tanzania, where imports of food are particularly low, partially due to a lack of access to global food markets.

Multiple studies have shown that annual crops suffer in drought conditions (Munishi et al., 2015; Msongaleli et al., 2015). Drought is a major concern among Tanzanian farmers because rain-fed agriculture is much more common than irrigated agriculture (Slegers, 2008). In particular, maize is considered a staple crop and comprises on average about 25% of caloric intake (Barreiro-Hurle, 2012). Because of this coinciding increase in drought and the vulnerability of staple crops in Tanzania, climate change is expected to take a major toll on food security in the country.

Nutritional deficiencies are not unique to low-income nations. They may, however, be more closely linked to environmental factors when citizens do not have the income or market access to deal with environmentally-related changes in food supply. Nutritional deficiencies in adolescents of the United States and Canada, for example, have been shown to be related to individual wealth and consumer preferences rather than overall supply (Vereecken et al., 2007).

Previous Literature on Determinants of Stunting and Anemia

Stunting

Several previous studies have sought to identify determining factors associated with childhood stunting. Stunting has been found to be associated with mother's schooling, birth size, and drinking water quality (Chirande et al., 2015). It may also be related to maternal height (Baig-Ansari, 2006; Özaltin, 2010). Other studies have shown that indicators of household wealth are the most important factor in determining stunting and wasting rates (Rannan-Eliya et al., 2013; Tiwari et al., 2014; Kanjilal et al., 2010). Additionally, several studies have demonstrated a causal relationship between frequency of diarrhea and both stunting and wasting (Sereebutra, 2006; Rahman et al., 2009), which implies a link between nutritional deficiencies and lack of access to a safe water supply. The relationship between sex and stunting has been assessed with different results. While some studies show that male children are significantly more likely to be stunted than females (Chirande et al., 2015), others show the opposite (Baig-Ansari, 2006).

Anemia

Anemia has also been shown to be commonly associated with household wealth indices (Pasricha et al., 2010; Halileh and Gordon, 2006). In addition, iron-deficiency anemia has been found to be determined by lack of consumption of certain iron-rich foods (Zlotkin et al., 2004). Wealth status and nutrition have synergistic effects: infants with low dietary intake of iron with low socioeconomic status are more likely to suffer from slow cognitive development than those with either higher iron intake or higher socioeconomic status (Lozoff et al., 2006). A significant relationship has also been established between stunting and anemia (Assis et al., 2004).

Food Security

Another way of looking at hunger and nutrition is through perceived food security. Food security is characterized by four major factors. Availability refers to the existence of a food supply within a country, and is comprised of domestic production and imports from abroad. Access refers to the ability of households to reach that supply, be it through market infrastructure or roads. Utilization, the third aspect of food security, refers to the ability of the household to safely and nutritiously prepare food. Finally, stability refers to the overall consistency and predictability of the above three aspects (FAO, 2015). The ability, or lack thereof, of families and communities to acquire food in the face of environmental challenges, such as droughts, is essential to food security.

Food security is often measured qualitatively through responses to questions on availability of and access to food. While measurements of height, weight, and other health outcomes are useful, so are responses to questions about number of meals eaten per day and the extent to which individuals worry about food availability. The most frequently cited causes of food insecurity, as measured by inadequate access to food, are poverty, environmental stressors, and political conflict (Misselhorn, 2005). Certain types of food consumption may also impact the ability to access food. In particular, meat access may help prevent childhood stunting in low-income setting (Krebs et al., 2011). Nutritional outcomes are often, but not always, linked to food security measures. For example, studies have found that the best predictor of stunting and wasting is household food security (Hackett et al., 2009; Baig-Ansari et al., 2006).

Research Aim

The objective of my project is to assess the extent to which environmental and land-use practices impact childhood stunting, wasting, and anemia. Do agricultural practices, such as the keeping or selling of crops and the use of irrigation, have more or less of an impact on childhood nutritional outcomes than other factors? My study adds to this literature reviewed above in two ways. First, it examines the environmental and land-use factors that lead to the food security measures mentioned above in order to assess the root cause of poor nutritional outcomes. Second, it compares the impacts of land use and agriculture on two different nutritional outcomes: stunting and anemia in children. Identifying the differences between such impacts is essential to better understanding their mechanisms and better evaluating possible interventions.

Study Area

The Mvomero District is located in the northern part of the Morogoro Region of Tanzania. Morogoro is one of 30 administrative regions, and is located on the eastern side of the country. Tanzania's 2012 national census estimated the entire region's population to be about 2.22 million people, while the population of Mvomero as of 2012 was 312,109 (URT, 2013). Mvomero is in total about 14,000 square kilometers (URT, 2003) and is located about 300 – 400 meters above sea level,. The average low and high temperatures are 20 and 30 degrees Celsius (Mlozi et al., 2006).

Mvomero is made up of four divisions, 17 wards, and 128 villages. As of 2012, the average household size was 4.3 people per household (URT,2013). The major crops of the Mvomero district are rice, maize, sugarcane, and sorghum. Keeping livestock in addition to raising crops is also common (Mlozi et al., 2006).

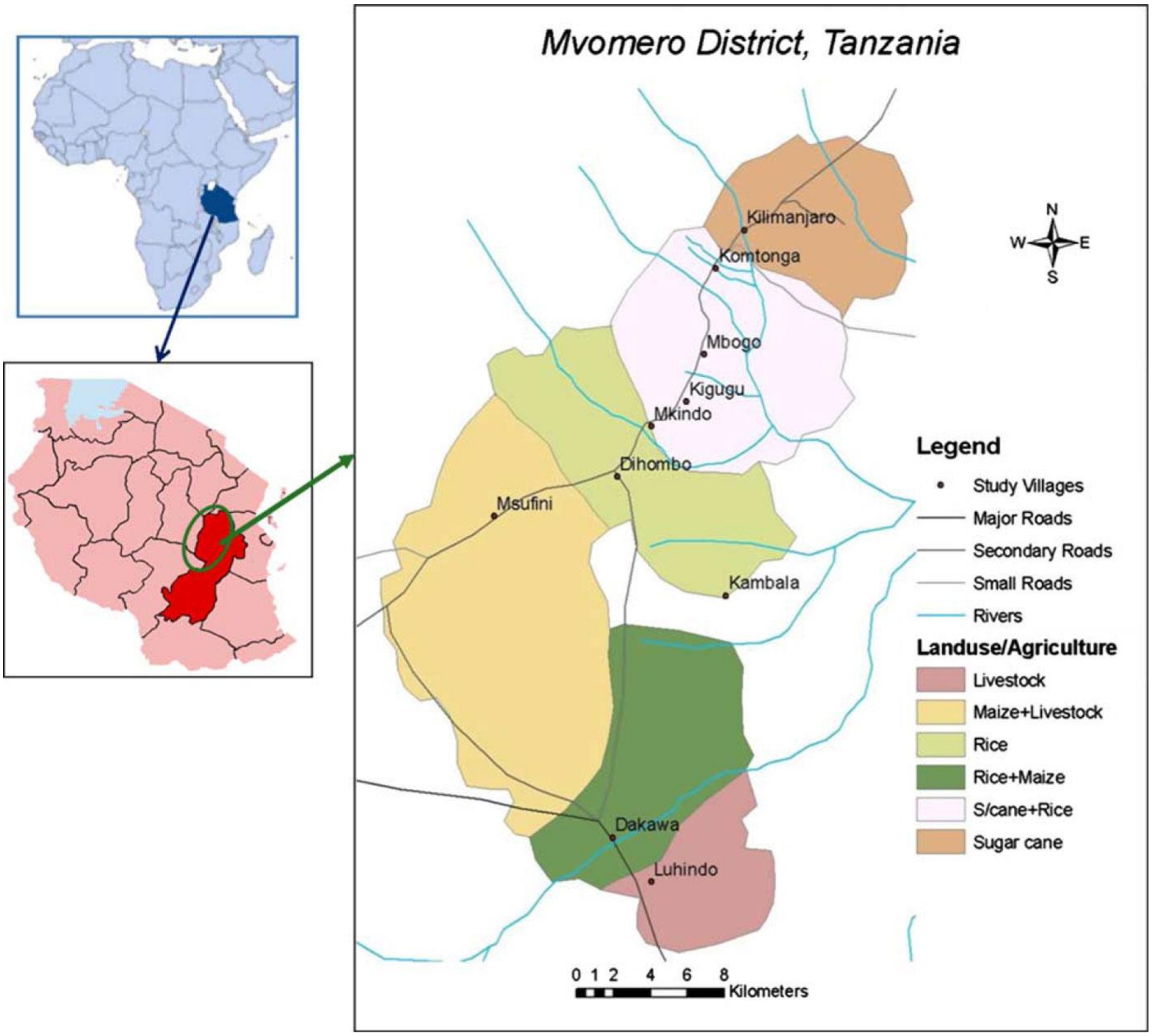


Figure 4: Map of Tanzania, with Mvomero district shaded (Dickinson et al., 2011).

Methods

This paper identifies land-use drivers of nutritional outcomes in young children and of households' perceived food security. I use logistic regression analysis to establish significant relationships between agriculture (measured by types of crops grown, crop selling, irrigation, and crop failure) and nutrition (measured by childhood stunting and anemia) and food security. My results apply specifically to the Mvomero district of Tanzania but I discuss possible relevance outside of that scope in the Discussion section.

Data

My data come from the Mvomero project, which used an implementation science approach to assess the changes in malaria outcomes between different interventions. The project included a baseline household survey and two rounds of interventions followed by additional household surveys (Kramer et al., 2014).

Of 65 original candidate villages, 24 villages were selected for the study. Villages deemed unreachable in the rainy season were excluded. Four subvillages were then randomly selected in each village. Once the subvillages were established, the researchers took out of the sample households without children under the age of five. From the remaining candidates, households were randomly selected, with about 40 households per village. The baseline study from 2011 is made up of 5,422 household members as observations.

This data has not yet been analyzed in the frame of nutrition and food security. This, combined with the fact that studying nutrition in a location with such high rates of stunting and anemia is important, was a key factor in the selection of this data for my project. As demonstrated in the literature review above, Tanzania's changing environment, and the challenges it poses for agriculture, also make it an ideal place to study the relationship between agricultural practices and nutritional outcomes.

Creation of Dataset

For the nutritional outcome analysis, each unit of observation is a child under five years of age, with each child's parametric information (sex, height, weight, hemoglobin concentration, and age) matched with the household's characteristics. To do this, each child observation was matched with the data supplied by the household head identified in each household. In one case, two individuals identified as the household head. The younger of the two was removed and the older was used. In cases where more than one child was listed for the same household, the household head's data is the same for each child in his or her household. I also omitted from regressions observations that I characterized as too extreme to be accurate and that were likely data entry errors. I omitted observations with height below 10 cm or above 150 cm and observations with weight over 40 kg. Overall, 1,927 observations of children under five were kept from an original 10,049 observations of all ages.

For the food security analysis, all observations from the original dataset with answers to the food security questions were included. This included responses not only from household heads but from all household members answering the questions. Overall, 3,275 responses included data on worry about running out of food and number of meals per day.

Outcome Variables

The nutritional outcome variables of interest are childhood stunting and anemia. In each year of the study (baseline and two intervention years), these data were collected in each of the study villages. Any member of a study household was eligible to participate in the collection of malariometric data at a central location in the village, either a health facility or school. Each individual reported basic demographic information such as age and sex, and measurements of height, weight, temperature, and other health indicators were taken. In addition, blood samples were obtained for measuring hemoglobin concentrations, which was necessary for assessing anemia (Kramer et al., 2014). With these data, all participants in the malariometric data collection process could be assessed for stunting and anemia.

Stunting is a measure of height for age. As described in the introduction to this paper, it has been shown to have severe and long-term impacts on quality of life. Here, stunting is measured relative to World Health Organization (WHO) standards. The standards cutoff is 2 Z-scores below the median. Thus, an individual is stunted under the following condition:

$$\text{Z-score} < -2$$

$$\text{where Z-score} = \frac{(\text{Observed Height−to−Age}) - (\text{Median Height−to−Age of Reference Population})}{\text{Standard Deviation of Reference Population}}$$

Anemia is also measured based on WHO standards. The following table shows the hemoglobin levels (at sea level) for each category of anemia in children aged 59 months or younger.

Table 1: Anemia categories by blood hemoglobin levels for children aged 59 months or younger.

Anemia Category	Hemoglobin Level (g/l)
No Anemia	110 or higher
Mild	100-109
Moderate	70-99
Severe	Lower than 70

Raw data on height weight, and hemoglobin concentrations in the data allowed for the coding of each individual as either stunted or not and as fitting into an anemia severity category.

In addition to the nutritional outcomes, I also assess impacts on perceived food security outcomes. Two food security questions were asked in the second intervention year: "For the last 12 months, to what extent were you worried that the food you had at your household would run out before you were able to get more? and "How many meals do you often eat in a day?" The coding of both of these variables is presented in Table 2.

Input Variables

One of the independent variables used in my analysis is whether or not a household grows a specific crop. The crops included in the dataset are rice, maize, sugar, banana, cassava, vegetables, and "other" crops. Because few households grow crops besides rice and maize, I combine the remaining crops into one "other crop" category. Type of crop might affect health outcomes for several reasons. First, each crop has its own nutritional profile. For example, some foods have higher concentrations of vitamin A than others, which is in turn associated with a lower prevalence of anemia (McLean et al., 2008). Second, some crops are more resilient to weather events or to wildlife consumption than others. It is thus important to understand the relationship between specific crops grown and nutritional outcomes.

In addition, I assess the impact of selling any crop relative to keeping all crops for home consumption. I expect that households that sell crops perform better in health parameters than those that consume all crops grown because I expect that households only sell crops when they have more than they need for home consumption. On the other hand, households with jobs aside from agriculture might actually be wealthier overall than those that sell crops as their main income. Those off-the-farm jobs may safeguard the household's individuals against adverse health impacts from nutritional deficiencies.

I also assess the impact of irrigation on health outcomes. Because the Mvomero district of Tanzania is prone to inconsistent rainfall (Paavola, 2008), I expect that households with irrigation systems are more likely to have sufficient food, and significantly better health outcomes, than those without irrigation. In addition, irrigation systems are a measure of wealth. Because of the upfront investment required to install such a system, the use of irrigation by a household indicates availability of capital.

Finally, the survey includes a question on crop failure. Respondents were asked, "In the past year, did you or anyone in your household experience any of the following events?" with one event being "crop failure." Assessing whether or not crop failure impacts the health of individuals within the household allows for an understand of resilience. If individuals suffer greatly nutritionally from a loss of crop productivity, this is an indication that they do not have a diversified set of options to fill in the gaps. Such an impact is thus expected to be tied to wealth: families that are able to purchase crops to fill in those gaps will suffer less than those who cannot afford to purchase supplemental food.

I included controls for sex, age, household size, and number of children under five in the household. In addition, I used three variables as controls for household socioeconomic status. Owning livestock, having a metal roof, and owning one's house all indicate some financial stability and were thus included.

The table below summarizes the input and control variables used in my analysis.

Table 2: Coding of input and control variables.

Variable	Description	Coding
Rice	Whether or not a household grows rice	1 if yes; 0 if no
Maize	Whether or not a household grows maize	1 if yes; 0 if no
Other Crop	Whether or not a household grows sugar, bananas, cassava, vegetables, or "other" crops	1 if yes; 0 if no
Irrigate	Whether or not a household irrigates any crops	1 if yes; 0 if no
Sell	Whether or not a household sells any crops	1 if yes; 0 if no
Crop Failure	Whether or not a household has experienced crop failure in the past 12 months	1 if yes; 0 if no
Female	Whether child is female	1 if yes; 0 if no
Age	Age of child in years	Years
Livestock	Whether or not the household owns any livestock	1 if yes; 0 if no
Metal Roof	Whether or not the household has a metal roof	1 if yes; 0 if no
Own House	Whether or not the household head owns the house	1 if yes; 0 if no
HH Size	Number of respondents in given household	Number of individuals
HH Kids	Number of children under 5 years old in given household	Number of individuals

Estimation Strategies

Based on my preliminary literature review and data availability, I developed the following eight questions for testing by regression analysis:

Impacts on stunting and anemia:

1. Is a household growing certain crops associated with stunting or anemia in its children?
2. Is a household selling any crops associated with stunting or anemia in its children?
3. Is a household irrigating any crops associated with stunting or anemia in its children?
4. Is a household experiencing recent crop failure associated with stunting or anemia in its children?

Impacts on perceived food security:

5. Is a household growing certain crops associated with the extent to which the household head worries about running out food or the number of meals eaten per day?
6. Is a household selling any crops associated with the extent to which the household head worries about running out food or the number of meals eaten per day?
7. Is a household irrigating any crops associated with the extent to which the household head worries about running out food or the number of meals eaten per day?
8. Is a household experiencing recent crop failure associated with the extent to which the household head worries about running out food or the number of meals eaten per day?

I ran the following models in Stata 14. The models with stunting as the outcome variable are assessed using logit regression. I chose to test impacts on hemoglobin concentration directly instead of on anemia category in order to increase the explanatory power of the anemia models. The hemoglobin models were therefore assessed using multiple linear regression.

Below are specifications used for each model. In each case, model 1 is a simple model assessing the impact of growing rice, maize, or other crops. These models include the covariates summarized in Table 2. For each outcome, I also include Model 2, which includes analysis of selling any crops, irrigating any crops, and crop failure. The crop failure variable was not, however, included in food security models because of the time lag present. Since the question on crop failure was asked only in 2011 and the food security questions were asked only in 2013, assessing the relationship between responses would imply assessing associations between a crop failure in 2010 and perceived food security in 2013. Because of this time lag, crop failure was not included in the food security models.

Relationships with nutritional outcomes:

1. $Stunting = \beta_0 + \beta_1(Rice) + \beta_2(Maize) + \beta_3(Other\ Crop) + \beta_4(Female) + \beta_5(Age) + \beta_6(Livestock) + \beta_7(Metal\ Roof) + \beta_8(Own\ House) + \beta_9(HH\ Size) + \beta_{10}(HH\ Kids) + \varepsilon$
   $Hemoglobin = \beta_0 + \beta_1(Rice) + \beta_2(Maize) + \beta_3(Other\ Crop) + \beta_4(Female) + \beta_5(Age) + \beta_6(Livestock) + \beta_7(Metal\ Roof) + \beta_8(Own\ House) + \beta_9(HH\ Size) + \beta_{10}(HH\ Kids) + \varepsilon$
2. $Stunting = \beta_0 + \beta_1(Rice) + \beta_2(Maize) + \beta_3(Other\ Crop) + \beta_4(Irrigate) + \beta_5(Sell) + \beta_6(Crop\ Failure) + \beta_7(Female) + \beta_8(Age) + \beta_9(Livestock) + \beta_{10}(Metal\ Roof) + \beta_{11}(Own\ House) + \beta_{12}(HH\ Size) + \beta_{13}(HH\ Kids) + \varepsilon$
   $Hemoglobin = \beta_0 + \beta_1(Rice) + \beta_2(Maize) + \beta_3(Other\ Crop) + \beta_4(Irrigate) + \beta_5(Sell) + \beta_6(Crop\ Failure) + \beta_7(Female) + \beta_8(Age) + \beta_9(Livestock) + \beta_{10}(Metal\ Roof) + \beta_{11}(Own\ House) + \beta_{12}(HH\ Size) + \beta_{13}(HH\ Kids) + \varepsilon$

Impacts on perceived food security:

1. $Worry\ about\ running\ out\ of\ food = \beta_0 + \beta_1(Rice) + \beta_2(Maize) + \beta_3(Other\ Crop) + \beta_4(Female) + \beta_5(Age) + \beta_6(Livestock) + \beta_7(Metal\ Roof) + \beta_8(Own\ House) + \beta_9(HH\ Size) + \beta_{10}(HH\ Kids) + \varepsilon$
   $Meals\ per\ day = \beta_0 + \beta_1(Rice) + \beta_2(Maize) + \beta_3(Other\ Crop) + \beta_4(Female) + \beta_5(Age) + \beta_6(Livestock) + \beta_7(Metal\ Roof) + \beta_8(Own\ House) + \beta_9(HH\ Size) + \beta_{10}(HH\ Kids) + \varepsilon$
2. $Worry\ about\ running\ out\ of\ food = \beta_0 + \beta_1(Rice) + \beta_2(Maize) + \beta_3(Other\ Crop) + \beta_4(Irrigate) + \beta_5(Sell)) + \beta_6(Female) + \beta_7(Age) + \beta_8(Livestock) + \beta_9(Metal\ Roof) + \beta_{10}(Own\ House) + \beta_{11}(HH\ Size) + \beta_{12}(HH\ Kids) + \varepsilon$
   $Meals\ per\ day = \beta_0 + \beta_1(Rice) + \beta_2(Maize) + \beta_3(Other\ Crop) + \beta_4(Irrigate) + \beta_5(Sell) + \beta_6(Female) + \beta_7(Age) + \beta_8(Livestock) + \beta_9(Metal\ Roof) + \beta_{10}(Own\ House) + \beta_{11}(HH\ Size) + \beta_{12}(HH\ Kids) + \varepsilon$

Results

Summary Statistics

Below are summary statistics for the children in the dataset. The children included in my analysis are all household members under the age of five years old.

Table 3: Summary statistics for children dataset.

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Female	1,953	0.507	0.500	0	1
Age (years)	1,953	2.418	1.230	0	5
HH Size	1,953	11.701	5.791	2	48
HH Kids	1,953	3.348	1.817	1	12

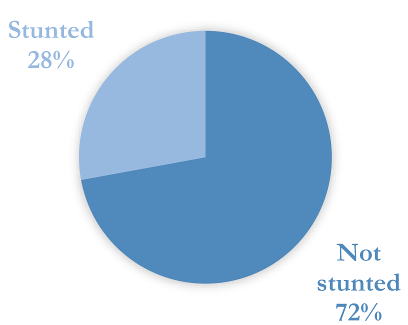
In addition, I include summary statistics for the food security data. Because these questions were only asked of respondents in 2013, I used all the data available instead of restricting the analysis to households with children under five years old as above.

Table 4: Summary Statistics for data used in food security analysis

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Female	3,295	0.503	0.500	0	1
Age (years)	3,295	20.354	16.209	0	80
HH Size	3,295	13.916	4.955	4	31
HH Kids	3,295	1.103	0.866	0	5

Visual Descriptive Results

Figures for two main outcome variables, stunting and anemia, are displayed below. Stunted is shown as a binary variable and is equal to 1 if the child is below the height-for-age value defined as stunting by WHO. Anemia is shown categorically and children are either not anemic or have mild, moderate, or severe anemia, also as defined by WHO standards.



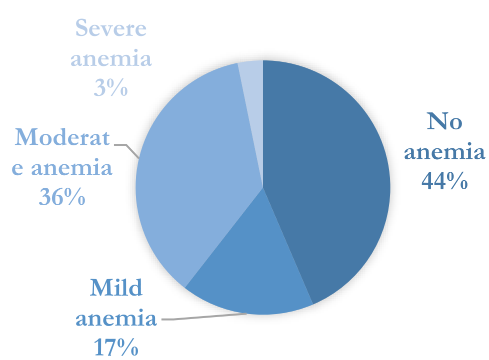


Figure 5: Proportion of children under five stunted (N=1837) and with each category of anemia (N=1686).

Below are the proportions of children stunted and with each category of anemia broken down by sex.

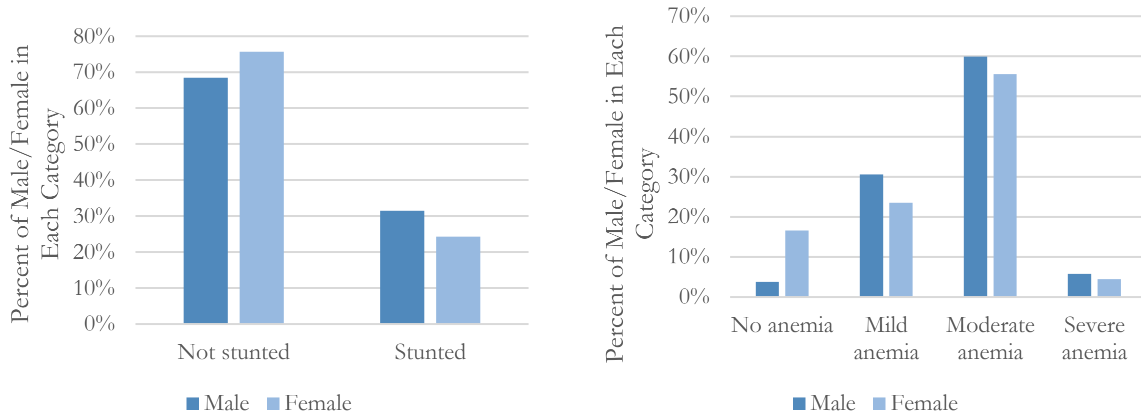


Figure 6: Proportion of children under five stunted (N=1837) and with each category of anemia (N=1686), broken down by sex. It appears that both stunting and anemia are more common in males than females.

Below are descriptive results for food security outcomes. These are the frequencies of responses by household heads to the two questions directly referring to perceived household food security. The questions were worded, "For the last 12 months, to what extent were you worried that the food you had at your household would run out before you were able to get more? and "How many meals do you often eat in a day?"

Worry about Food:

Meals per Day:

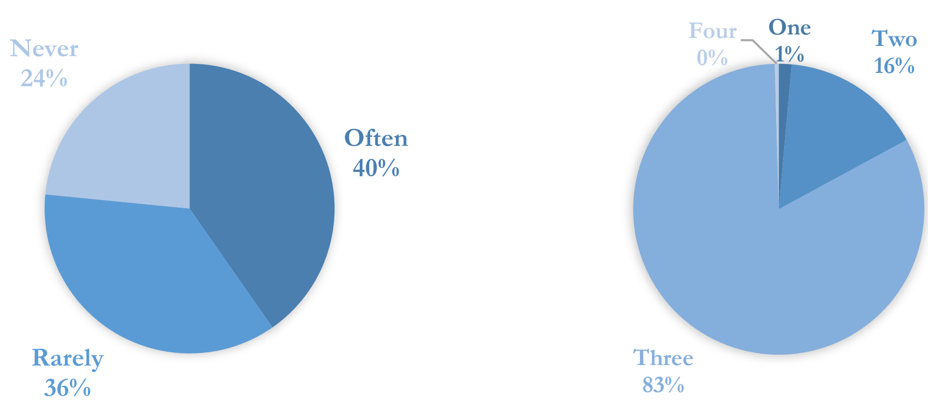


Figure 7: Responses to food security questions. On the left are the frequencies of responses to "For the last 12 months, to what extent were you worried that the food you had at your household would run out before you were able to get more?" (N=913) and on the right are responses to "How many meals do you often eat in a day?" (N=913).

Descriptive results for input variables are displayed below. First, results on proportions of households growing rice, maize, and other crops are shown. Next, a visual representation of whether households sell any crops and irrigate any crops are included. Finally, results for whether or not households have experienced a crop failure in the past year are presented.

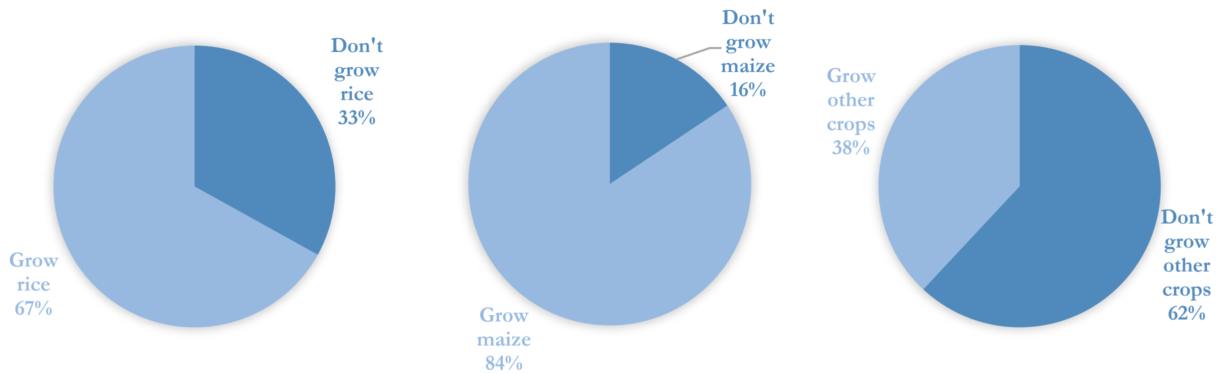


Figure 8: Frequencies of growing rice (N=1927), growing maize (N=1926), and growing other crops (1953). The category "other crops" includes sugar, bananas, cassava, vegetables, and the response "other crops."

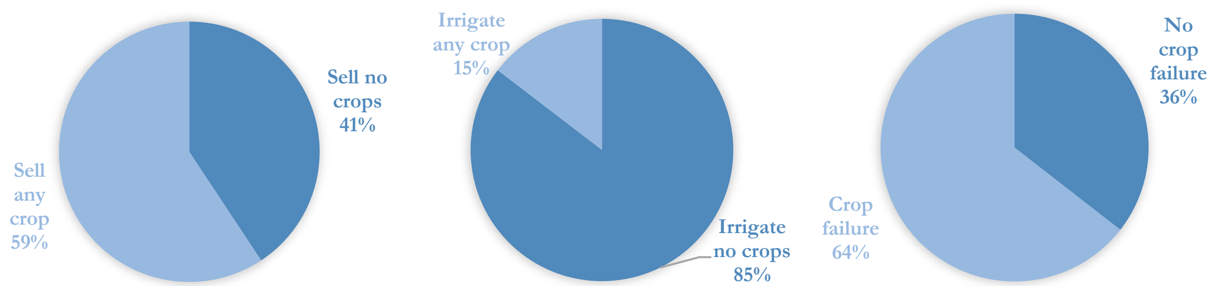


Figure 9: Frequencies of selling any crop (N=1953), irrigating any crop (N=1953), and experiencing crop failure within the past year (N=1900).

Finally, the table below summarizes values of control variables included in the children's nutrition regressions and in the food security regressions.

Table 5: Frequency of owning livestock, having a metal roof, and owning one's house in children's nutrition data.

	Yes	**No**	**N**
Livestock	1,154 (59%)	797 (41%)	1951
Roof	1,188 (61%)	765 (39%)	1,953
Own House	1,650 (84%)	303 (16%)	1,953

Table 6: Frequency of owning livestock, having a metal roof, and owning one's house in food security data.

	Yes	**No**	**N**
Livestock	1,991 (60%)	1,302 (40%)	3,229
Roof	2,192 (67%)	1,103 (33%)	3,295
Own House	2,875 (87%)	420 (13%)	3,295

Regression Results

Stunting

Stunting results are presented with anemia results in Table 7. The first model looks only at the relationship between stunting and crops grown. The second model adds variables for irrigation, selling crops, and crop failure. In assessing predictors of childhood stunting, a few trends emerge. While growing rice and maize both appear to have no significant relationship with the probability of stunting, growing one or more of the crops in the "other crop" category is positively associated with stunting. This is true of both forms of the stunting model. On the other hand, selling crops and irrigation are both associated with reduced likelihood of childhood stunting in the household. Likelihood of stunting is significantly lower for females than for males, and the probability that a child is stunted increases with age. Notably, the pseudo R^2 values of these models are low, with 0.0225 for the simpler model and 0.0275 for the model with more explanatory variables.

Anemia

The two models displayed for hemoglobin are set up in the same way as the two stunting models. The outcome variable is hemoglobin, rather than anemia category, because the additional variability in the hemoglobin variable allowed for a better fit of the model. Maize is positively associated with higher hemoglobin variables (which in turn corresponds to lower anemia severity) in both versions of the model. Hemoglobin levels are on average lower in male children than female, and increase with age. None of the household income or wealth proxy variables were significantly related to hemoglobin. The adjusted R^2 value for model 1 is .0961 and for model 2 is 0.0956

Food Security

Food security results are displayed in Table 8. A few significant relationships emerge when examining relationships with frequency of worrying about running out of food. This question had three possible answers: "often" (coded as 1), "rarely" (coded as 2), or "never" (coded as 3). An increase in answer category for this question thus indicates greater perceived food security. This food security measure is significantly positively associated with irrigation (households who irrigated any crop were less likely to report feeling food secure) and negatively associated with selling any crop. Both livestock ownership and metal roofs are associated with more frequent worry about food. There is also a significant negative relationship between household size and food security: more household members (measured here as the total number of respondents from a given household) is associated with lower perceived food security. The pseudo R^2 value was 0.0158 for model 1 and 0.0127 for model 2.

Irrigation has the same positive effect on the other measure of food security, number of meals per day. Growing maize, however, is negatively associated with number of meals per day. Having a metal roof, livestock, and owning one's house are all associated with more meals eaten per day. Household size and number of kids under five years old in the households are not significantly related to number of meals eaten per day. Pseudo R^2 values for models 1 and 2 are 0.0132 and 0.0152 respectively.

Results of tests for multicollinearity are presented in Appendix B.

Table 7: Relationships between agricultural practices/outcomes and children's nutritional outcomes (stunting and hemoglobin concentration). Results of logit regression and multiple regression analysis.

	Stunted		Hemoglobin	
	(1)	(2)	(1)	(2)
Rice	0.107	0.215	-0.103	-0.083
	(0.12)	(0.13)	(0.07)	(0.08)
Maize	-0.067	-0.144	0.311**	0.334**
	(0.16)	(0.17)	(0.10)	(0.10)
Other Crop	0.267*	0.376**	0.096	0.099
	(0.11)	(0.12)	(0.07)	(0.08)
Irrigate		-0.379*		-0.092
		(0.17)		(0.10)
Sell		-0.270*		0.062
		(0.12)		(0.08)
Crop Failure		0.22		-0.104
		(0.12)		(0.07)
Female	-0.379***	-0.365***	0.191**	0.185**
	(0.11)	(0.11)	(0.07)	(0.07)
Age	0.208***	0.206***	0.337***	0.337***
	(0.04)	(0.05)	(0.03)	(0.03)
Livestock	0.121	0.15	0.109	0.087
	(0.12)	(0.12)	(0.07)	(0.07)
Metal Roof	-0.098	-0.115	0.113	0.105
	(0.11)	(0.12)	(0.07)	(0.07)
Own House	-0.121	-0.118	-0.062	-0.075
	(0.16)	(0.16)	(0.10)	(0.10)
HH Size	-0.01	-0.01	0.005	0.007
	(0.01)	(0.01)	(0.01)	(0.01)
HH Kids	0.108**	0.099*	-0.014	-0.014
	(0.04)	(0.04)	(0.02)	(0.02)
Constant	-1.549***	-1.522***	9.240***	9.253***
	(0.26)	(0.27)	(0.16)	(0.17)
N	1789	1789	1710	1660
Pseudo R^2/Adjusted R^2	0.0225	0.0275	0.0961	0.0956
Prob < Chi^2/Prob < F	0.00	0.00	0.00	0.00

Standard errors in parentheses.
* p<0.05, ** p<0.01, *** p<0.001

Table 8: Relationships between agricultural practices/outcomes and food security responses. Results of ordered logit regression analysis.

	Worry Food		Meals Per Day	
	(1)	**(2)**	**(1)**	**(2)**
Rice	0.01	(0.02)	-0.082	-0.148
	(0.08)	(0.08)	(0.10)	(0.11)
Maize	0.12	0.16	-0.381**	-0.379**
	(0.10)	(0.10)	(0.14)	(0.14)
Other Crop	0.10	0.12	-0.175	-0.217*
	(0.07)	(0.07)	(0.09)	(0.10)
Irrigate		0.337***		0.339**
		(0.09)		(0.13)
Sell		-0.217**		0.002
		(0.07)		(0.10)
Livestock	-0.381***	-0.386***	0.379***	0.384***
	(0.07)	(0.07)	(0.09)	(0.09)
Metal Roof	-0.260***	-0.274***	0.309**	0.306**
	(0.07)	(0.07)	(0.10)	(0.10)
Own House	(0.08)	(0.07)	0.292*	0.290*
	(0.11)	(0.11)	(0.13)	(0.13)
Female	0.03	0.04	-0.095	-0.089
	(0.07)	(0.07)	(0.09)	(0.09)
HH Size	0.038***	0.035***	0.003	0.002
	(0.01)	(0.01)	(0.01)	(0.01)
HH Kids	-0.245***	-0.251***	-0.002	0.00
	(0.04)	(0.04)	(0.06)	(0.06)
School	(0.14)	(0.14)	0.171	0.169
	(0.07)	(0.07)	(0.10)	(0.10)
Cut 1 Constant	-1.328***	-1.439***	-4.467***	-4.494***
	(0.17)	(0.17)	(0.29)	(0.29)
Cut 2 Constant	0.483**	0.382*	-1.091***	-1.115***
	(0.17)	(0.17)	(0.23)	(0.23)
Cut 3 Constant			5.988***	5.975***
			(0.37)	(0.37)
N	3193	3193	3209	3209
Pseudo R^2	0.0158	0.0127	0.0143	0.0162
Prob < Chi^2	0.00	0.00	0.00	0.00

Standard errors in parentheses.
* p<0.05, ** p<0.01, *** p<0.001

Discussion

Explanations of Results

Growing rice had no significant impact on any of the assessed outcomes. This was an unexpected result because rice is an important cash crop in the Mvomero region (Wassena et al., 2013). The lack of relationship may be due to the fact that the income benefits of producing rice are picked up by another wealth proxy variable, such as having a roof. Maize, on the other hand, was significantly associated with two outcomes: hemoglobin an d meals per day. Growing maize is significantly associated with higher hemoglobin concentrations in children. This relationship runs contrary to the significant association between growing and maize and eating fewer meals per day. While maize itself (unless fortified) is not high in nutrients that reduce the chance of anemia in children (Faber et al., 2005), there may something else associated with growing maize and with lower anemia. For example, another crop may typically be grown with maize that helps reducing anemia, or families may make enough income from maize to purchase other foods high in vitamin A or iron, which increases hemoglobin concentrations. Anemia is also related to malaria (Kramer et al., 2014). If the land used for growing maize is less conducive to mosquitos surviving, the link between maize and anemia may actually be malaria-related instead of nutritionally driven. Also, the "other crop" category may indicate that a household grows some crops for subsistence rather than for cash, which would explain its positive association with stunting.

If the crop income and anemia story is true, we should expect to see that selling any crop is associated with lower anemia levels. There is, however, no significant relationship between the crop selling variable and anemia, although there is a slightly significant ($p<0.05$) relationship between selling any crop and stunting. A more significant relationship exists between selling any crop and worrying about running out of food: household heads worry less frequently when they sell crops. This makes sense if we assume that households keep food for themselves and then sell their surplus, or if we believe that households selling crops make enough income from sales that they are able to purchase enough food. On the other hand, no significant relationship emerged between selling crops and number of meals per day. This might indicate that households engaging in cash cropping may be selling food they would otherwise eat. This discrepancy between these impacts of selling crops on food security may be explained by the fact that food security answers in my dataset are only from household heads. It may be that household heads tend to eat fewer meals themselves and prioritize giving food to children. In addition, number of meals per day may not actually be indicative of the amount of food available on a given day. We do not know whether households facing a short food supply decrease the number of meals per day or merely decrease the size of each meal.

Irrigation led to more consistent results. Irrigating any crop is associated with a lower chance of stunting and is also associated with less frequent worry about running out of food. In addition, households with irrigation also report more meals per day on average. It is important to note, however, the low overall frequency of irrigation: it is difficult to draw conclusions from a variable when only about 15% of households irrigate any crop.

The effect of having experienced a crop failure in the past year was not significantly associated with either nutritional outcome in children. This may indicate a more long-term process of becoming stunted or anemic. It might also be a result of the timing of the study. The question on crop failure was only asked in 2011 and referred to the previous 12 months. Having more data on crop failure, such as knowing whether households had experienced crop failures over a longer, several-year period, would be helpful in drawing meaningful conclusions about the effect of such failures on nutrition. Such an analysis will become increasingly important in modeling future impacts of more severe weather.

A few relationships observed in control variables in regressions on stunting and hemoglobin are also worth discussing. Being a female child was strongly significantly related to lower chances of both stunting and anemia. This is contrary to much of the literature on childhood nutrition, which tends to find that girls are more likely than boys to suffer adverse effects of undernutrition (Baig-Ansari et al., 2006). In addition, chances of stunting increase with age and hemoglobin levels also increase with age. In other words, one bad outcome (stunting) is more likely to occur with older children but the other (anemia) is statistically less likely as children grow older. This distinction may also be a matter of timing: while children may be able to recover from negative effects of anemia with time (for example with a changing diet as they grow older), stunting takes longer to emerge as a problem.

The effect of household size was not significant on stunting and anemia, but was significant on worrying about running out food. This food security result was opposite expectation: larger household sizes were related to less worry. On the other hand, higher numbers of kids under the age of five increased worry about food. This makes sense if we expect that larger numbers of household adults means more people contributing to the total household food supply, while children are solely consumers. Interestingly, neither variable was significantly related to the number of meals per day. It could be that the number of meals per day is less influenced than the size of each meal. An area for further study would be to analyze actual caloric or nutrient intake and its association with household size and number of children.

Implications of Results

The main goal of assessing predictors of nutritional problems in children and perceived food security is to assess potential solutions. It appears that there is no one crop that, when grown, leads to better nutritional outcomes in children. In addition, I had hypothesized that a recent crop failure event would be a significant predictor of low nutrition and food insecurity. This would have led to the conclusion that improving resilience to causes of crop failure, such as drought or wildlife invasions, would be substantially beneficial. Similarly, if either irrigation or selling a crop (ie. engaging in some kind of cash cropping) had been significant and consistent predictors of improved outcomes, the results would have pointed to a need for increased prioritization of access to those activities in the Mvomero region. Instead, given the low explanatory power of my models, my main conclusion is that childhood nutrition and food security are influenced by more than just the way that a household grows food.

In addition, the fact that fewer children in a household were significantly linked to lower levels of worry about running out of food, at least as perceived by the household head, is a call for lower birth rates and smaller overall household sizes. Women with access to birth control and to more opportunities outside of the home tend to have fewer children on average (Malhotra, 2005). Such a trend indicates that perhaps a more social and cultural shift in the role of women in society would lead to a dramatic improvement in food security.

Limitations of Analysis

One cause for concern with my results is the low pseudo R^2 values on all models. While the results do indicate some significant predictors of nutritional and food security outcomes, the fact that the models explain a relatively low amount of variation in the outcome indicates that there are other predictors, perhaps unobserved, that explain these outcomes. Identifying and measuring these unobservable predictors, or pursuing a form of random assignment, would allow for the incorporation of such characteristics into the analysis.

A possible explanation for some mixed results, especially in the nutritional outcomes, is the definition of those outcomes. Because I coded these outcomes in my data using the World Health Organization standards, I am missing some of the variation in height-for-age. This is a matter of tradeoffs: in order to maintain simplicity and ease of comprehension of stunting, I forfeited some of this detail. It is worth noting that this decision leads to a problem with thresholds: being just below the WHO height threshold for stunting at a given age is an entirely different outcome than being just above it, although the actual underlying nutrition and health of those two observations would be very similar.

One major limitation of the food security analysis lies in the timing of the data. Data were collected on land use and agricultural practices in the 2011 round of interviews, while the food security questions were only asked in 2013. This was particularly concerning with regard to the crop failure variable, which was asked in 2011. Because the question asks if a crop failure had occurred in the household in the previous twelve months, the analysis relates that occurrence with perception of food security three years later. I therefore chose to omit the crop failure data from the food security analysis. My analysis would have rested on the assumption that there is something systemically true about households that experienced a crop failure in the twelve months leading up to the 2011 analysis that was relevant in explaining food security in 2013. Because I found this assumption improbable, I was unable to assess relationships between crop failure and food security.

Conclusion and Next Steps

This paper examined potential causes of nutritional deficiencies and food insecurity in the Mvomero district of Tanzania. Using data on household land use practices in 2011 and health outcomes of children in each household in 2011 and 2013, I performed logit and ordered logit regressions on the relationships between land use practices and events and outcomes. I found a significant negative relationship between growing maize and childhood anemia and a significant positive relationship between growing other crops and stunting. In addition, selling crops and having some form of irrigation appear to reduce childhood stunting, while a recent crop failure is associated with childhood anemia. I also found that having fewer children and having a metal roof were both significantly related to more positive food security responses. While my results do not point to one solution or intervention that might improve nutritional outcomes for households in the Mvomero district, they do point to the complicated nature of nutrition and food security and emphasize the importance of a varied approach.

Nutritional deficiencies in children have long-term effects both on physical health and on economic well-being. Eliminating such negative impacts, and improving household perceived food security, are integral to the Sustainable Development Goal of eliminating hunger by 2030. Meeting such a goal, however, requires a deeper understanding of the root causes of undernutrition and food insecurity, and available solutions. While identifying statistical relationships as in this paper is a helpful exercise, isolating the actual causal impacts of agricultural practices on these outcomes is essential. One method for pursuing this avenue of future research is through random assignment of treatments. For example, researchers allocating irrigation systems randomly to households will be better able to isolate the causal impact of irrigating crops on nutrition and food security. In addition, longer time frames of data and greater numbers of observations will continue to add to the robustness of future research on the topic. Such progress will allow us as a global community to allocate our time and resources most effectively to ending hunger worldwide.

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Appendix A: Additional Information on Data.

Table 9: List of variables used and years of data availability.

Variable Name	2011	2013
Sex	X	X
Age	X	X
Relationship to HH head	X	X
Pregnant (self-report)	X	X
Education level	X	X
DV for village	X	X
Agriculture Variables		
Main econ/social/envi concerns	X	
Main health concerns	X	
Record of death in HH	X	X
Record of adverse economic events in HH	X	
Crops grown, amount	X	
Use of irrigation	X	
Livestock ownership	X	
Health/Nutrition Variables		
Temperature	X	X
Height	X	X
Weight	X	X
Arm Circumfrence (U5s)	X	X
Spleen enlargement (Y/N) (under 15 years)	X	X
Anemia HGB (g/L)	X	X
Food Security Variables		
Worried about food insecurity		X
Number of meals eaten per day		X
Household Status Variables		
Main econ/social/envi concerns	X	
Main health concerns	X	
Record of death in HH	X	
Record of adverse economic events in HH	X	
Number of rooms	X	
Housing construction	X	X
House ownership	X	
Land Ownership (acres)	X	
Drinking water source	X	
Energy source	X	
Toilet facility	X	
HH ownership of listed items	X	
Decision-making on expenditures (who?)	X	
Decision-making on health care (who?)	X	

Appendix B: Multicollinearity Diagnostics of Data

Table 10: Results of collinearity test on all covariates. Tests were performed using the Collinearity Diagnostics test ("Collin") by Phillip Ender. In general, VIF values lower than 2.5 imply a lack of problematic multicollinearity.

Variable	VIF	Square Root VIF	Tolerance	R-Squared
Rice	1.26	1.12	0.7946	0.2054
Maize	1.17	1.08	0.8559	0.1441
Other Crop	1.21	1.1	0.8286	0.1714
Irrigate	1.14	1.07	0.8747	0.1253
Sell	1.24	1.11	0.8089	0.1911
Crop Fail	1.12	1.06	0.8914	0.1086
Female	1.02	1.01	0.9782	0.0218
Age	1.02	1.01	0.9827	0.0173
Livestock	1.11	1.05	0.9033	0.0967
Metal Roof	1.13	1.06	0.8885	0.1115
Own House	1.14	1.07	0.8771	0.1229
HH Size	1.74	1.32	0.5748	0.4252
HH Kids	1.71	1.31	0.5853	0.4147
Mean VIF	1.23			

Appendix C: Additional Results

Below are results of propensity score matching (PSM) analyses performed as a robustness check on the regression results presented above. Propensity scores represent an observation's probability of being treated given the values of all covariates included. The covariates used in this analysis are the same as in the regression analysis above. Observations are then matched based on these propensity scores. The treatment variables used are also the same as above: whether a household grows rice, maize or another crop; whether the household irrigates any crops, whether the household sells any crops, and whether the household has experienced a crop failure in the past 12 months. Results are presented above. Significant PSM results indicate significant relationships between the treatment and "outcome" variable holding constant observations' probability of having that treatment. While the PSM method therefore holds constant the impacts of other observable characteristics in these relationships and reduces concerns about functional form assumptions in regressions, it still does not resolve the concern of omitted variable bias in the results due to unobserved household characteristics.

Table 11: Propensity score matching results for stunting (number of matches = 1, number of matches for standard error = 4).

Treatment Variable	Coefficient	Standard Error	z	P>|z|	95% Confidence Interval		N
Rice	0.028	0.032	0.88	0.377	-0.034	0.090	1741
Maize	-0.013	0.064	-0.2	0.844	-0.138	0.113	1791
Other Crop	0.116*	0.040	2.88	0.004	0.037	0.195	1791
Irrigate	-0.129	0.104	-1.24	0.216	-0.333	0.075	1741
Sell	-0.078*	0.031	-2.51	0.012	-0.138	-0.017	1741
Crop Failure	0.065*	0.030	2.2	0.027	0.007	0.123	1741

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

Table 12: Propensity score matching results for hemoglobin (number of matches = 1, number of matches for standard error = 4).

Treatment Variable	Coefficient	Standard Error	z	P>|z|	95% Confidence Interval		N
Rice	0.281	0.216	1.3	0.194	-0.143	0.705	1665
Maize	0.185	0.170	1.09	0.276	-0.148	0.518	1715
Other Crop	0.085	0.129	0.66	0.509	-0.167	0.337	1715
Irrigate	-0.647	0.346	-1.87	0.061	-1.325	0.031	1665
Sell	0.039	0.099	0.39	0.695	-0.155	0.233	1665
Crop Failure	-0.180	0.104	-1.73	0.084	-0.383	0.024	1665

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

Table 13: Propensity score matching results for worry about food (number of matches = 1, number of matches for standard error = 4).

Treatment Variable	Coefficient	Standard Error	z	P>|z|	95% Confidence Interval		N
Rice	0.147**	0.057	2.6	0.009	0.036	0.258	3118
Maize	-0.004	0.047	-0.09	0.929	-0.097	0.089	3196
Other Crop	0.012	0.029	0.42	0.673	-0.045	0.070	3196
Irrigate	-0.256**	0.080	-3.21	0.001	-0.412	-0.099	3118
Sell	0.065*	0.029	2.22	0.027	0.007	0.122	3118

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

Table 14: Propensity score matching results for meals per day (number of matches = 1, number of matches for standard error = 4).

Treatment Variable	Coefficient	Standard Error	z	P>|z|	95% Confidence Interval		N
Rice	-0.024	0.048	-0.5	0.620	-0.118	0.070	3131
Maize	-0.120***	0.024	-4.99	0.000	-0.168	-0.073	3209
Other Crop	0.001	0.015	0.09	0.928	-0.027	0.030	3209
Irrigate	0.040	0.075	0.54	0.590	-0.106	0.187	3131
Sell	-0.014	0.020	-0.72	0.474	-0.053	0.024	3131

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