THE PRACTICE OF INTEGRATING LEGUMES IN THE CROPPING SYSTEM: EVIDENCE OF IMPACT ON FOOD SECURITY AND NUTRITIONAL OUTCOMES OF SMALLHOLDER FARMERS IN UGANDA

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ABSTRACT

THE PRACTICE OF INTEGRATING LEGUMES IN THE CROPPING SYSTEM: EVIDENCE OF IMPACT ON FOOD SECURITY AND NUTRITIONAL OUTCOMES OF SMALLHOLDER FARMERS IN UGANDA.

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Legumes play an important role in a nutrition-focused agricultural strategy because they provide a myriad of environmental and nutritional benefits. To realize those benefits, legumes can be integrated as mono-cropping, intercropping, and rotation in a cropping system. The literature on the impact of legume-based cropping has been growing but not addressed in the case of Uganda. This study examines the impact of legume-based practices on food security and nutritional outcomes of small-holder farmers using a nationally representative household survey for Uganda. A multi-step approach was used. In the first step, I assess the impact of different legume-based cropping on household level food security outcomes (i.e., calorie and protein produced, crop income, HDDS and MAHFP), and child level nutrition outcomes (i.e., extent and prevalence of stunting, underweight and wasting) along the agriculture-food security-nutrition impact pathway. As a second step, I attempt to identify the pathway through which legumes integration influences consumption and nutrition-related outcomes. The first step results suggest a positive and significant association of some legume-based practices with production outcomes (e.g., robust results for legume-non-cereal rotation), and mixed or weak results for child nutrition outcomes. The impact on food consumption related outcomes (i.e., HDDS and MAHFP) remained insignificant in all cases except for legume non-cereal intercropping. In the second step, the study identified crop income as the main pathway to improve MAHFP and to reduce the prevalence of wasting, and production as the main pathway to increase HDDS.

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CHAPTER 1. INTRODUCTION

1.1. Background and Motivation

Food insecurity and malnutrition have been amongst the pressing problems facing many developing countries (FAO 2008; FAO 2017; Smith et al. 2006). Despite increased efforts towards alleviating food insecurity and malnutrition, progress towards reducing these problems has been below the desirable level (World Bank, 2007), especially in Africa and Asia. According to the study by Smith, Alderman and Aduayom (2006) on 12 Sub-Saharan African (SSA) countries, the prevalence of food insecurity was lowest in Uganda (37%) and highest in Ethiopia (76.4%). A study by FAO indicates fluctuating trends in the prevalence of malnutrition in SSA; it steadily declined from 28.1% in 2000 to 20.6% in 2010 but saw an upward trend with an increase to 22.7% in 2016 (FAO, 2017).

There are many strategies to address the problem of food insecurity and malnutrition. These include improvements and investments in education (Lipton et al. 1998; Gaiha 1993), health system (Croppenstedt and Muller 2000), economic growth and price stability (Timmer 2000), climatic change, shock and conflict mitigation strategies (Wheeler and Von Braun 2013 ; Teodosijevic 2003; Schmidhuber and Tubiello 2007), and political transformation (Smith and Haddad 2015). Agricultural productivity growth through improved technology and better crop management practices is also considered an important strategy towards alleviating food insecurity and malnutrition, especially since agriculture is the mainstay for the majority of the population, and an important contributor to national gross domestic product (GDP) in many developing countries (Wiebe 2003, Godfray et al. 2010).

Even though many agricultural technologies help in boosting productivity, they are either costly or not readily accessible to smallholder farmers. As a result, farmers fail to maintain productivity and are vulnerable to shocks in their resource base, the environment, and the economy overall. Apart from that, low rate of technology adoption and inappropriate farming practices consequently trigger soil degradation, decrease crop productivity, food availability, and increases in food insecurity. According to the study by Ibrahim (2013), the percentage of Ugandan farmers using improved seeds was around 6%, whereas that of inorganic inputs was much lower during the past five years. The adoption rate was especially low for farmers with less education and land size, and lacked access to credit, information, extension services and affordability.

Among the myriad of crops grown by small-holder farmers in developing countries, legumes[1] (see Appendix A; Figure A 1) are one of the nutrient rich food crops that play an important role in agriculture. The ability to fix atmospheric nitrogen and supplement other non-legumes with mineral nitrogen make legumes essential components within various farming systems and are often promoted as part of a sustainable intensification strategy (Messina 1999; Ncube et al. 2009; Giller 2001). Legumes are important sources of protein, vitamins, micronutrients, and supplemental income. They also allow farmers to sell and consume seeds in green stages between harvests and can be stored in the dry stage after harvest without any loss of their nutritional content. Moreover, legumes have high demand (i.e., part of the main diet in many developing countries) and marketability in many Sub Saharan African countries (Chianu et al., 2011). In recognition of the multi-faceted benefits that pulses and legumes provide to farmers and consumers, the Food and Agricultural Organization of the United Nations had declared the year 2016 as the International Year of Pulses.

There are many ways legumes can be integrated in the cropping system of smallholder farmers to realize their environmental and nutritional benefits. These include mono-cropping,[2]

[1] Legumes crops include lentils, peanuts, peas, beans, and other podded plants (Messina 1999)

[2] Mono-cropping is the practice of planting a sole crop on the same land for a given growing season.

intercropping[3], and rotation[4] (Anders, Potdar and Francis 1996; Manda et al. 2017). These practices offer different types of advantages to smallholder farmers. Mono-cropping is often promoted as a strategy to increase the productivity of the crop itself, whereas inter-cropping and rotation are promoted more as strategies to increase the productivity, and sustainably intensify the whole cropping system. Continuous crop cultivation of any crop without fallows and input use deteriorates land quality and productivity. Crop rotation, especially with legumes, helps break the pest cycle and provides the benefits to the following crop from the residual nutrients left in the soil.

Even tough intercropping may allow farmers to make intensive use of the limited land they have (Dwivedi et al. 2015), help in improving soil fertility through nitrogen fixation, conserves soil due to land coverage, reduces the need for complementary inputs like fertilizer, and allows farmers to have diversified means of income from growing multiple crops at one time (Kabunga, Dubois and Qaim 2014; Fujita and Ogata 1992), there are clear disadvantages of intercropping as it may also increase competition for water and nutrients, can increase pest pressure, create difficulty in managing weeds and overall may result reduction in total productivity making management and selection of crops to be intercropped difficult (Lithourgidis et al 2011; Thierfelder, Cheesman and Rusinamhodzi 2012).

Despite the potential for higher productivity of legume based practices, the impact of legume mono-cropping, rotation, and inter-cropping is highly variable, and depends on the soil and crop type (Ojiem et al., 2006). These practices alone do not guarantee higher productivity. Their contribution to smallholder farming system is also subject to different socioeconomic and

[3] Intercropping is the practice of growing more than one crop in a specific plot, and at a particular point in time. For a plot of land in a given growing season, the practice of intercropping and mono-cropping are mutually exclusive.
[4] Crop rotation is growing different crops each year/season over the same land. For a plot of land, the practices of rotation, intercropping and mono-cropping are not mutually exclusive over time. For example, a plot of land rotated with two different crops over two consecutive seasons could have been mono-cropped or inter-cropped in any given season. In other words, a given plot of land could be under the practice of rotation as well as intercropping and/or mon-cropping.

agroecological factors. Thus, understanding the effects of different ways of integrating legumes in the cropping system, on household food security and nutrition outcomes within the socioeconomic context in which smallholders operate, is the focus of this study. I use Uganda as a case study to address this issue.

Uganda was the first country to introduce legume cultivation in 1906 within the East African region (Byenkya 1988). According to the 2005/06 survey of 4.2 million agricultural households, the major crops grown in Uganda are maize (86.5 %), beans (80.8 %), cassava (74.3 %), banana (73.1 %), and other cash and noncash crops (Uganda Bureau of Statistics 2007a, p. 46). Ugandan agriculture is dominated mostly by subsistence farming, scattered/fragmented small land size, low use of improved seeds, fertilizer, and pesticides (FAO 2010), and lack of extension services (BakamaNume 2010, p. 215). Uganda has a vast portion of arable land with diverse soil types. However, due to lack of appropriate conservation practices soil degradation has been a pressing problem (BakamaNume 2011; Olson and Berry 2003).

Over the past years, many studies have focused on understanding the linkages between agriculture and nutrition (Manda et al. 2017; Magrini and Vigani 2016; Sauer et al. 2016; Kirk, Kilic and Carletto 2017; Azzarri et al. 2015; Kim, Mason and Snapp 2017). A recent study by Sauer et al. (2016) assessed the impact of legume-based cropping on food security in Zambia. The study analyzed the effects of cereal-legume intercropping/rotation, and anyother legume-based cropping for the subample of cereal producing households.The study found strong effect (i.e., statistially significant and postive) effect of cereal-legume rotation, little or no statisitcally signifcant effect of cereal-legume intercropping, and postively significant effect of legume-other practices (i.e., legume intercropping/rotation with non-cereal crops or legume mono-cropping) on different indicators of household welfare, including food security. Among the three legume-based cropping technologies they examined, the effect was much stronger in the case of cereal-legume rotation, while that of cereal-legume intercropping and legume-other practices was not robust compared to cereal legume rotation.

To the best of my knowledge, within the context of Uganda, the impact of such legume-based cropping on food security and nutritional outcomes of farming households has not been studied. Building on the analytical framework developed by Sauer et al. (2016), this study contributes to this gap by providing similar evidence on the impact of legume-based cropping on food security using a nationally representative dataset from Uganda. But it goes beyond the study by Sauer et al. (2016) or other previous studies by also examining the impact of legume-based cropping on nutrition outcomes. The goal of my research is to assess the pathways by which legumes can potentially impact household welfare and food security indicators, and whether these effects translate into nutritional outcomes for children.

In this study, I use four waves of nationally representative Living Standard Measurement Survey (LSMS) data collected from smallholder farming households in Uganda. The panel nature of this dataset allows me to use one of the rigorous methodological approaches and techniques, namely the fixed effect model. My analyses focus on five types of outcome variables that are considered necessary conditions for achieving and measuring food security (Coates et al. 2013; Leroy et al. 2015), namely crop income, calorie production, protein production, Household Dietary Diversity Score (HDDS), and Months of Adequate Household Food Provisions (MAHFP). In addition, I use anthropometric measurements of children below five years of age to assess the impact of the legume-based cropping on nutritional outcomes, namely stunting, wasting, and underweight, and examine the production and income, and food security effects on these child level nutritional outcomes.

My thesis is organized as follow. In chapter 2, I present the review of literature on agriculture and food security linkages, existing methodological approaches pertinent to my research topic, conceptual framework and research questions addressed. In chapter 3, I describe the data, sampling techniques, and specification of empirical strategy and models. In chapter 4, I discuss the results and main findings, followed by conclusions and recommendations in chapter 5.

CHAPTER 2. LITERATURE REVIEW

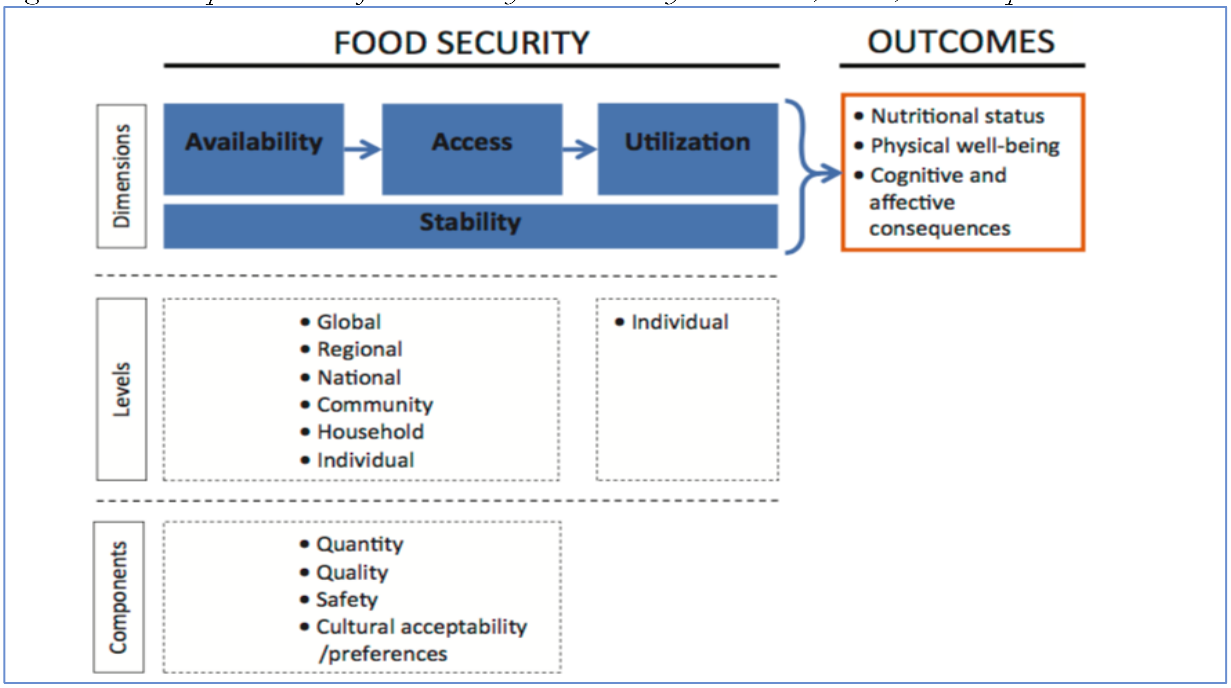
The literature review is presented in four sections. The first section introduces the concept of food security, various definitions found in the literature and reviews literature on agriculture and food security linkages. The second section reviews the existing literature and methodological approaches used to assess the impact of agricultural practices/technologies in general, and legume based-practices/cropping in particular on food security and nutritional outcomes. The conceptual framework underlying the pathways from agriculture to food security and nutrition outcomes follows in the third section, and the last section explains the main research questions addressed.

2.1. Introduction to the Concept of Food Security

The concept of "food security" at macro and micro level has evolved, diversified, and advanced over time (Maxwell 1996). The earlier definition of food security had several drawbacks; at "macro" level, food security was defined as the overall production stock in a given year. Globally and nationally, food security retained the supply-side perspective of the overall food system and had the same meaning as "self-sufficiency." According to that definition of food security, for any country to remain food secure, it was expected to produce all types of food required by its nationals. The standard definition of food security which was stated during the World Food Summit in 1996 was that "Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life" (FAO, 1996). Unlike former definitions on food security, this definition emphasizes the nutritional composition and food safety besides the availability, access, and utilization of food to meet daily dietary requirements.

Figure 1 illustrates a framework developed by Leroy et al. (2015) in which food security is depicted in terms of four dimensions, namely--availability, access, utilization, and stability. This framework further demonstrates that food security can be defined and studied at global, regional, national, community, household and individual level. Component-wise, it represents quantity, quality, safety and cultural acceptability or preferences (Leroy et al. 2015; Staatz et al. 2009).

Figure 1: The Complex Nature of Food Security: Food Security Dimensions, Levels, and Components



Source; Leroy et al. (2015)

The relationship between agriculture, food security, and nutrition is not linear, and is the result of an interaction of many processes. Due to multidimensionality, it lacks robust conceptual/theoretical framework that depicts linkages from agriculture to food security (Pangaribowo, Gerber and Torero 2013; Haddad 2000). Also, approaches that illustrate the causal pathways (either directly or indirectly) through which agriculture impacts food security and nutrition varies depending on the level, dimension, and component of food security that is being addressed.

There are many frameworks put forth and discussed in the literature that conceptualize the causal link between agriculture-food security-nutrition (Carletto, Zezza and Banerjee 2013). Among these, the framework developed by Herforth and Harris (2014) focuses on household level linkages and illustrates how agriculture, through investment on new technologies or farming practices, impacts productivity and how the environment interacts through the existing practice and further affects the nutrition and health conditions of farming households. In this framework, the major pathways comprise production, income, and women empowerment.

Food production is among the main factors affecting the food security of farming households, especially in developing countries. However, availability of food from own production does not guarantee access to food, required nutrients, and food security at all times (Carletto et al. 2013). Moreover, its impact on nutritional outcomes depends on the quality, quantity, type, seasonality, and availability of food produced for consumption, which further depends on the existing market situation and each household's decision-making processes (Herforth and Harris 2014). Besides, it is not very common for farming households to produce all types of food crops needed for a quality diet. Instead, they sometimes use their land to specialize in crop production, and produce surplus to generate income, which may allow households to access diversified diets. Thus, higher productivity per unit of land or other inputs used may contribute to food security and higher nutritional level through increased farm/crop income, assuming there is access and availability of nutritious and affordable food in the market (Herforth and Harris 2014; Manda et al. 2017; Haddad 2000).

Many studies have been conducted to examine whether higher agricultural productivity has linkages to increased income and dietary diversity of smallholder farmers (Pellegrini and Tasciotti 2014; Kirk, Kilic and Carletto 2017; Snapp and Fisher 2015; Sibhatu et al. 2015). According to Engel's law, the effect of income on food consumption is higher for poor than wealthier households because of the higher income elasticity of food for poor people, particularly in terms of calorie and micronutrient consumption (Deaton 2018; Skoufias, Tiwari and Zaman 2011). Higher income may improve dietary intakes of farming households, not only through access to diversified and nutritious diets but also through increased spending on household's health and sanitation, as a supplement for healthy living. Moreover, evidence suggests that women with full control over resources are more likely to allocate them better than men, and make pro-nutrition decisions for children (Haddad, Hoddinott, and Alderman 1997). Hence, women's empowerment, as a third pathway may play a prominent role not only in women's household consumption and expenditure decisions, but also their own and their children's health and nutrition outcomes, which can influence children's future productivity and income potential (Bhutta 2013; Herforth and Harris 2014).

2.2. Overview of Existing Literature and Methodological Approaches

Technology adoption is an endogenous choice, which depends on a set of household and socio-economic factors, and it is difficult to disentangle its effect from any other household decisions or external factors. The literature on the impact of agricultural technologies on food security in SSA is not very extensive, although it has grown in recent years. Many studies have found positive impact of technology adoption on productivity and food security (for e.g., Kassie et al., 2012; Kabunga et al. 2014; Magrini and Vigani 2016; Manda et al., 2017; Jaleta et al. 2018), but they represent a specific context and are not generalizable. Moreover, due to lack of available data, many of these studies are unable to address all dimensions of food security (Carletto et al. 2013).

A study by Magrini and Vigani (2016) tried to look at the impact of technology adoption (i.e., inorganic fertilizer and improved maize seed) on food security in Tanzania, using one year cross-sectional data from Tanzania National Panel Survey data series . The focus of the study was assessing the effect on four pillars of food security, namely availability, access, utilization and stability. The study addressed the issue of selection bias by using propensity score matching (PSM). The PSM method quantifies the impact of adoption based on similar observable covariates of adopters and non-adopters. To control selection bias and unobserved heterogeneity, and as a robustness check, endogenous switching regression model was used. However, due to the cross-sectional nature of the data, the study was unable to capture the long-term effects of adoption on food security. Similarly, Jaleta et al. (2018) studied the impact of improved maize varieties on food security by using nationally representative cross-sectional data for Ethiopia. The study also used endogenous switching regression model as means to control endogeneity and selection bias.

Manda et al. (2017) looked at the ex-ante effects of maize-soybean rotation on household food security using experimental and observational data from household surveys conducted by the Institute of Tropical Agriculture (IITA) and the International Maize and Wheat Improvement Centre (CIMMYT), respectively. The study assessed the impact of maize-soybean rotation on changes in household income and poverty alleviation using market level economic surplus approaches. To estimate surplus changes on individual households, as opposed to the changes in market surplus, the study incorporated household level analysis along with the market level information. Their results suggested a positive impact of maize-soybean rotation on income and poverty reduction of small-scale farmers compared to monocropping. A limitation of the data, which was cross-sectional, was limited control over unobservable factors of the analysis.

Methods based on panel data are more advantageous than cross-sectional data and enable researchers to capture the heterogeneous effect of the existing trends within a specific context. In the last decade or so, the use of panel data techniques in the impact evaluation literature has increased steadily. Moreover, researchers have been developing panel data models that are compatible with specific data and variables of research interest, which has led to consistency and efficiency in estimation. Some recent studies focusing on agriculture-nutrition linkages that have used panel data include: Azzarri et al. 2015, Sauer et al. 2016, Kirk et al. 2017, and Kim, Mason and Snapp 2017. My research builds on the panel data methodologies of some of these recent studies, which are described below.

The study by Sauer et al. (2016) looked at the impact of legume-based technologies on household welfare using the Rural Agricultural Livelihoods Survey (RALS) panel data of two waves for Zambia. The motivation behind the study was to assess the production and income pathways through which legume-based technologies, such as intercropping and rotation impact food security among cereal growing households. The outcome variables used reflect different indicators along the pathway from production of calories and proteins to crop income, Household Dietary Diversity Score, and Months of Adequate Household Food Provision. Due to the differences in the variable type (continuous vs. count) amongst these outcome indicators, the study used different models, namely household fixed effect model, correlated random effects negative binomial, and pooled ordinary least squares models. The study also used two stage least square instrumental variables model as a control for self-selection bias and endogeneity problem. The study found a positive and significant impact of cereal-legume rotation on household welfare, little effect of cereal-legume intercropping, and mixed effect of other legume-based technologies; mono-cropping, rotation/intercropping with non-cereal crops on household welfare indicators.

Adequate animal product consumption, associated with livestock ownership, can potentially impact the nutritional status of farming households and children. Due to high prevalence of livestock ownership but higher stunting rate among children in Uganda, Azzarri et al. (2015) tried to look at the effect of livestock ownership and animal source food (ASF) products' consumption on nutrition outcomes of children living in rural areas, using two waves of Living Standard Measurement Survey (LSMS) panel data for Uganda. The study identified a substantial difference in ASF consumption between livestock owners and non-owners; owners tend to consume higher amount of ASF than non-owners. It further indicated (i)a significant effect of large ruminant ownership on dairy food consumption but not on beef consumption, (ii) a non-significant effect of small ruminant ownership on sheep and goat meat consumption, but positive effect of poultry ownership on chicken consumption. In translating the positive effect of ASF consumption on child nutrition outcomes, the study found a weak correlation between livestock ownership and child nutrition outcomes (underweight and wasting) and no association with stunting. However, the results were sensitive to the specific age groups of children; with higher effect on older children (children between ages of 24 to 59 months). The study did not find any effect of ASF consumption on nutrition outcomes of older age groups like lactating mothers and women at reproductive age and called for further research on the impact of other consumption components that affect nutrition.

Higher income is often associated with better nutritional outcomes. However, does the source of income influence the nutritional outcome? The study by Kirk et al. (2017) addressed this question by estimating the effect of different sources of income on short-term child nutrition outcomes. The study examined the effects of crop and non-crop income; different sources of income within agriculture, and the overall income of the household regardless of the source. The study used three waves of LSMS panel data for Uganda and empirically analyzed the data using child fixed effect model with and without controlling for child-level characteristics. Specific to Uganda, the impact of agricultural income nutrition outcomes was negative indicating (i) a negative and significant impact of the share of crop income and crop consumption on the height-for-age z-scores (HAZ), implying low nutrient crops production and own crop consumption, (ii) non-significant impact of the shares of livestock and wage income and conversely, positive and highly significant effect of self-employment income signaling higher correlation with child nutrition outcomes. Due to lack of convincing and strong instrumental variables for income, the study findings are not conclusive on the causality of income sources on child nutrition outcomes.

Households usually adopt more than one technology, but most studies in the literature has focused on assessing the impact of a single technology. Single-technology studies do not capture the differential impact of technologies per se. With main intention of filling this gap on literature, the study by Kim, Mason, and Snapp (2017) looked at the differential impact of sustainable farming practices (SFM) on child nutrition outcomes within a framework if multiple technology adoption decision. To capture the effect of unobserved heterogeneity and selection bias, the study used multinomial endogenous switching regression model. The study finding indicated positive effect of all treatment practices on height for age z-scores (HAZ), but only sustainable intensification had a positive effect on weight for age z-scores (WAZ). Overall, the study found a positive effect of sustainable farming practices on child nutrition outcomes.

The review of literature presented in this section highlights many factors that can affect food security and nutrition outcomes namely (i) agricultural technologies embedded in input use such as fertilizers and improved seeds, (ii) animal source products, (iii) income and different sources of income, and (iv) sustainable farming practices such as intercropping or rotating cereal or non-cereal crops with legume crops. However, these studies represent specific contexts and situations, and are not generalizable. Motivated by the importance of legume crops in Uganda, this research studies the impact of legume-based cropping on household food security and household level nutrition outcomes of small-holder farming households in Uganda.

My study contributes to the literature in two ways. First, by looking at the effects of all the ways legumes can be integrated in cropping systems—i.e., monocropping, intercropping with cereal and non-cereal crops, and rotating with cereal and non-cereal crops. Second, it extends the analysis to include the effects of legume-based cropping on child nutritional outcomes, and examining how legume-based cropping impact on production and income outcomes translate to child nutrition outcomes. Moreover, to the best of my knowledge, there is no study done on the impact of legume-based cropping in Uganda, hence this study also contributes to country-specific literature on the impact of legume-based cropping on indicators of food security and nutritional outcomes along the agriculture-nutrition linkages pathway.

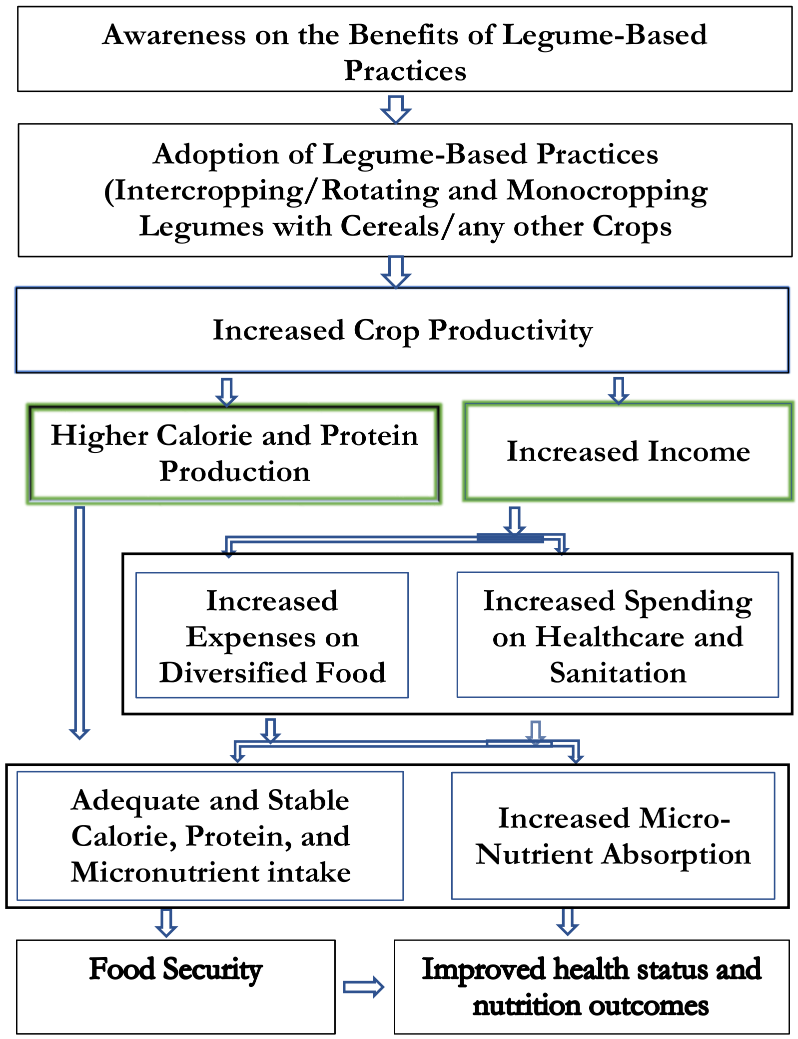
2.3. Conceptualizing Legume-Based Cropping and Food Security Linkages

Improved agricultural technologies are considered necessary for attaining higher productivity, and many countries have experienced structural transformation via adoption of agricultural technologies. Having said that, higher productivity via agricultural technology does not guarantee higher nutritional level at all times. Moreover, many of the existing agricultural technologies are not easily accessible and affordable for smallholder farming households, leading to low adoption rates (Lunze et al. 2012).

For a nutrition-focused agricultural strategy, legumes are good alternatives, especially for small-scale farmers in developing countries. In the context of Sub-Saharan Africa, legumes are widely grown and are easily adaptable at small scale production. As mentioned earlier, intercropping/rotating legumes with cereals or any other crop has a multitude of benefits and can potentially impact food security and nutrition of farming households through production, income, and women's empowerment pathways.

Figure 2 illustrates these pathways through which legume-based cropping such as rotation, intercropping, and mono-cropping are conceptualized to impact household food security and nutrition. In the production pathway, the biological characteristics of legume crops such as the ability to fix nitrogen and enhance soil quality come into play and can induce higher total productivity of the cropping system compared to systems without such legume integration (Giller, 2001; Hartwig and Ammon, 2002; Manda et al., 2017).

Figure 2: Conceptual Pathway of Legume-Based Cropping Impact on Food Security and Nutrition.



Source; Adapted based on Sauer et al. (2016)

As shown in Figure 2, households that adopt legume-based practices have a higher potential for increased productivity, given other conditions are constant. Increased productivity further might lead to more production of calories, protein, and other micro-nutrients, which implies increased food availability for the household. It also implies increased income from sales of surplus harvest. Higher income further may increase household's expenditure and ability to purchase nutritional and diversified diets. Similarly, higher crop income may also increase household spending on sanitation and health products/services, which can interact positively with food consumption to enhance individual's nutrient absorption capacity, and potentially reduce incidence of diseases, leading to better nutritional outcomes. Even though empowered mother's role is vital in the proper implementation of infant and young child feeding practices, and the overall consumption and expenditure decisions within the household, due to lack of data this study did not look at the third main path way, women's empowerment

In summary, in this study the biological, nutritional and environmental benefits of legume-based cropping and its interaction with the socio-economic setting of small-scale farmers in developing countries are hypothesized to impact the household welfare, namely food security and nutrition, through the production, and income. Hence, I try to test the hypothesis on whether legume-based practices impact food security and nutrition outcomes, within the context of Uganda, identify potential pathways and address the following research questions

2.4. Research Questions Addressed

In the context of the food security conceptual framework depicted in figure 1, the focus of my research is on the quantity and quality components of food security at the household and individual levels. The indicators I use in my analysis reflect the availability, access, and utilization dimensions of food security, and on nutritional status outcomes with a focus on children less than five years of age (more discussion on these indicators is in the following chapter). These indicators fall across different nodes of the impact pathway depicted in Figure 2.

As mentioned earlier, legumes play an important role in both the production and dietary systems of Ugandan farming households. In the context of Uganda, my research addresses following research questions:

1. Do legume-based practices—i.e., cereal-legume rotation, cereal-legume intercropping, legume mono-cropping, and other ways of integrating legumes in the cropping system, impact food security and nutritional outcomes of farming households in Uganda? Do these impacts vary across these practices?

2. What are the main pathways through which agriculture is linked to food security outcomes within the Ugandan smallholder farming context?
3. Do the production and income effects of legume-based cropping (if any) translate to improvements in child nutritional status as reflected in the prevalence of child level malnutrition indicators?

CHAPTER 3. DATA AND METHODS

3.1. Data and Sampling

This study uses four waves of the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) data for Uganda, which took place between years 2009 and 2014. Out of 783 enumeration areas (EAs) across the country, 322 were selected for the Uganda National Panel Survey (UNPS) in 2009/10. The EAs within each stratum were selected with implicit stratification as urban/rural and district with equal probability. The surveyed sample of the population includes urban/rural residents in Central without Kampala, Eastern, Northern, and Western regions. The survey used two-stage stratified random sampling and is a nationally representative panel survey for Uganda.

The survey was conducted with structured questionnaires administered at the household and community level. For households that actively engaged in agriculture, the survey includes agricultural modules. The household questionnaire includes information on general household demographic characteristics, consumption, expenditures, assets owned, educational background, financial and transport services, and anthropometrics measurement for children 6-59 months. The agriculture questionnaire includes landholding owned and rented, inputs used, and crops grown and sold by each household. The community questionnaire inquiries about service availability in the community, education, health services, transport and work infrastructure. The agriculture module was conducted twice a year to account for seasonality in production, consumption, and marketing. The first agricultural season is from January to June and the second agricultural season goes from July to December (Interviewer manual, 2009). The harvesting months for both cereals and legumes is from May to August, in the first season, and September to January, in the second season (see Appendix A: Figure A 2) (FAO, 2010).

Appendix A: Table A 1 shows the brief summary on the number of households surveyed, observations pre and post data cleaning, and number of observations across the four panels (waves) of datasets used in this study. Column 6 of Appendix A; Table A 1 represents the number of households that have full information on both agriculture and household questionnaires. Across all four waves, the unbalanced panel includes 9,018 observations. Out of these observations (N=9,018), 14.07%, appeared in one round only, 7.85% in two rounds, 29.24% in three rounds and 48.84% in all four rounds.[5] For the panel data models used in this paper, 14.07% of households that appeared only in one round were dropped from the analysis. Furthermore, to examine the effects of crop rotation with legumes in a given agricultural year, the analysis was restricted to those households that grew crops in both the seasons in a year. The analytical sample finally used in this study includes an unbalanced panel of 6,489 observations across 2097 households, which represents about 72% of total number of observations across all four rounds.

Due to the large loss of observations over the four survey rounds, I conducted an attrition test using the method outlined in Wooldridge (2002; p. 585). I created a new attrition variable (att_{t+1}), that takes the value 1, if a household appears in at least two rounds and grew crops in two seasons in a year, and taking the value zero otherwise, relative to a given year. Using the overall unbalanced panel, I regressed all dependent variables on all explanatory variables and the attrition variable (att_{t+1}) using the fixed effect model. Based on that test, I failed to reject the null hypothesis of no attrition bias in all outcome variables. The coefficient on the attrition variable was non-significant in all of the outcome variables with p value ranging from 0.21 to 0.69.

The study further incorporated child anthropometrics measurement data and tried to look at the impact legume-based practices on the prevalence of stunting, underweight, and wasting among

[5] Using 2009 as the base sample, the attrition rate was minimal in 2010/11 and 2011/12, but 2013/14 only 67.4 % of households were among those that were interviewed in the previous wave (2011/12), while 32.6% were rotated.

children. For this analysis, I use a subsample of households that have children between ages of 6 and 59 months. Moreover, for my analysis I only included households that have child level anthropometrics data in at least two survey rounds and grew crops in two seasons in a given agricultural year. In total, this analysis on child level nutritional outcomes is based on an unbalanced panel of 3,490 children aged 6 to 59 months across 922 households.

3.2. Treatment Variables

Following Sauer et al (2016), this study used five main treatment variables and presented each treatment variable as a (1) dummy/binary; taking the value one if the household is a user of the given legume-based cropping and zero otherwise; and as a (2) continuous variable representing the area planted under each type of legume-based cropping. The binary treatment includes cereal-legume intercropping, cereal-legume rotation, legume non-cereal intercropping, legume non-cereal rotation, and legume monocropping. Similarly, the continuous treatment variables represent total area planted to each type of legume-based cropping. The binary treatment variable captures the prevalence of each practice, while the continuous treatment variable captures the extent of use of each practice. For the sake of convenience, I refer the treatment variables collectively as "legume-based cropping/practices". Note that these are all household level decisions and thus not mutually exclusive treatment variables. In other words, a legume growing household could potentially be integrating legumes in the cropping system in one or multiple ways in any given year (see the explanation below on the definition of treatment variables).

In this study, I created the five-treatment variables using crop level data of the Agriculture module. As a first step, I generated four groups of crops namely (i) "Cereals" such as barley, maize, finger millet, rice, sorghum and wheat; (ii) "Legumes" comprising all legume crops commonly grown in Uganda, namely, beans, chickpeas, cowpeas, field peas, groundnuts and pigeon peas; (iii) "Other crops" defined as all other crops excluding cereals and legumes and includes perennial crops, biannual crops and sugar cane as well, and (iv) "Non-legumes" includes all crops except legumes. Based on the four groups of crops, I classified each plot as "cereal plot" if a plot has at least one cereal crop, "legume plot", if a plot has at least one legume crop, "other-crops plot", if a plot comprises at least one non-cereal or non-legume crop; and "nonlegume plot" if a plot does not include any of the legume crops.

In the next step, I identified each plot as "Pure/free-stand" and "mixed plot." and then defined each plot as (1) cereal-legume intercropping, if the plot consisted of both cereals and legumes in one season; (2) cereal-legume rotation if the plot consists of cereals the first season and legume in the second season, and vice versa; (3) legume non-cereal intercropping if the plot consists of legumes and other crops in the same season; (4) legume non-cereal rotation if the plot consists of legume plot in the first season and other crops in the second season, or vice versa, and (5) legume-monocropping if the plot consists of only legume crop in a year. Lastly, I categorized each household as a user or non-user of the five legume-based cropping practices if the household practiced them in at least one of its plots.

3.3. Outcome Variables

According to the definition noted earlier (and as indicated in Figure 1), food security incorporates four dimensions--namely, availability, access, utilization, and stability. Household food access refers to the adequacy in quality and quantity of dietary requirements for a productive life (Swindale and Bilinsky 2007), whereas utilization refers to the biological capacity and making the best use of available food for productive and healthy life. Indicators of nutritional status such as anthropometric measures for children reflects the utilization component of food security. In assessing the pathways through which agriculture impacts food security and nutrition, this study includes food security outcome indicators derived either directly from the dataset or by calculating them. The outcome variables used include calorie produced per capita per day, protein produced per capita per day, gross/net crop income, weekly HDDS (Household Dietary Diversity Score), and MAHFP (Months of Adequate Household Food provisions). All of these indicators measure one or multiple dimensions of food security. For example, calorie and protein produced per capita per day represent food availability, gross and net crop income represents both food availability and food access, HDDS represents food access dimension, and MAHFP represents both food access and food stability. Also, based on anthropometrics measures, I also used indicators of nutritional status of children based on the z-scores and whether a child was stunted, underweight or wasted, measuring the utilization dimension of food security.

Naturally, all crops have diversified nutritional content, and to capture the impact of legume-based cropping on food security and nutrition, it is inappropriate to use the total amount of production of different crops in aggregate as an indicator of food availability. As such, researchers have designed means whereby all crops can be converted to a standard metric; converting total production to calorie and protein produced. To calculate this, I first converted the total crop production harvested into a standard and common unit (Kg). After converting all crops into a standard unit (Kg), the total kilograms of each crop were converted to their equivalent calorie (calories) and protein (grams) content. The study used crop calorie data conversion table and google conversion rate of major crops[6].

Even though economic growth/increased income per capita has a potential to alleviate food insecurity, metrics on the food access node of agriculture-food security pathway are weakly correlated to increased income, while those on the food utilization node are highly correlated to increased income (Tandon et al. 2017). To capture that, I included gross and net crop income representing the availability and access dimensions of food security. The gross crop income

[6] Available at; http://iopscience.iop.org/17489326/8/3/034015/media/erl472821suppdata.pdf.

represents the monetary value of all the crops grown by each household; i.e., the gross value of crop production (i.e., quantity harvested multiplied by crop price), while the net crop income is gross income less the costs of purchased seed, organic/inorganic inputs, pesticides, transportation, and hired labor. To account for inflationary measurement bias, I adjusted the gross/net crop income to 2009 market value using the composite consumer price index for food crops in Uganda[7]. Similarly, all other monetary variables used in the analysis were converted to the 2009 monetary value. The net crop income might not necessarily correlate with the food access path of the food security but might induce consumption of different quality foods, reflecting higher correlation to the dietary intake node of the food security pathway (recall Figure 2).

HDDS is a frequently used measure of food access component of food security, and measures the quality of food consumed at the household level. According to the Food and Nutrition Technical Assistance (FANTA)[8]for HDDS measurement guideline, HHDS is measured based on 12 food groups/categories; 1. Cereals, 2. Root and tubers, 3. Vegetables, 4. Fruits, 5. Meat, poultry & offal, 6. Eggs, 7. Fish and seafood, 8. Pulses/legumes/nuts, 9. Milk and milk products, 10. Oil/fats, 11. Sugar/honey, and 12. Miscellaneous. The standard HDDS indicator is a count variable ranging from 0 to 12, representing the number of food groups/categories (out of 12 categories) consumed by each household in the past one day, reflecting the variety of foods consumed by the household. In the LSMS dataset for Uganda, each household was asked about their food consumption behavior in the past seven days rather than past one day. Thus, in the absence of data on foods consumed in the past 24 hours, which is used to estimate the standard HDDS, I use the weekly HDDS based on the past one week recall period. Many previous studies have used such weekly HDDS indicator as a

[7] Available at ; https://www.ubos.org/onlinefiles/uploads/ubos/cpi/junecpi2011/June_2011_CPI.pdf, pp 6 ; https://www.ubos.org/onlinefiles/uploads/ubos/cpi/cpiMarch2015/FINAL%20CPI%20Release%20-March%202015.pdf; pp 5).

[8] Available at; https://www.fantaproject.org/sites/default/files/resources/HDDS_v2_Sep06_0.pdf.

measure of access to diet quality (Kibrom and Qaim 2016, Snapp and Fisher, 2015). Similar to these previous studies, I use a weekly HDDS indicator, as opposed to the standard daily HDDS indicator.

The MAHFP is a count variable asking households to report on the number of months they did not have enough food to meet household's food needs (i.e., were food insecure). The MAHFP indicator variable is the difference between 12 and the number of months household was food insecure. Usually, MAHFP is considered an indicator of food access. However, given the fact that it captures food access over the past 12 months, in a way it is also a measure of food stability. In other words, a household who has access to food all 12 months (MAHFP=12) prior to the interview time, and also implies more stability in food security over that time period, and vice versa. According to Swindale and Bilinsky (2007), MAHFP data should be collected during the time before harvest to avoid the bias of recall time. For the household survey I used, the data was collected throughout the year and there could be potential bias as farmers might report the state of food security in the interview date rather that year-round estimates (i.e., recall bias could be an issue as well). Also, the survey did not collect information on MAHFP in the second wave (2010/11). Thus, the analysis in this paper for this outcome indicator is based only on three waves of panel data (2009/10, 2011/12, and 2013/14).

The study included two child nutrition outcome indicators, namely (1) stunting[9], which is an indicator of chronic (long-term) malnutrition, (2) wasting[10], which is an indicator of acute malnutrition as a result of chronic disease or starvation; it is an indicator of current and short-term nutritional status of children (WHO 2010), and (3) underweight[11], which is a composite measure of stunting or wasting or both, and thus complex to interpret. These indicators were created using child level data for children aged 6-59 months. In doing so, I First created child level HAZ (height for

[9] If Height for Age (HAZ) is below 2 standard deviations from the mean/median
[10] If Weight for Height (WHZ) is below 2 standard deviations from the mean/median
[11] If Weight for Age (WAZ) /Weight for Height (WHZ) or both are below 2 standard deviations from the mean/median

age), WAZ (weight for age), and WHZ (Weight for height) z-scores[12] using the guidelines from 2006 WHO child growth standards; zscore06 Stata command (Leroy 2011). After calculating the z scores for HAZ, WAZ and WHZ, I defined each child as wasted/underweight/stunted, based on the z-score values. A child with a HAZ/WAZ/WHZ z-score of below negative two standard deviations (-2 SD) from the reference median/mean is categorized as stunted/underweight/wasted. Finally, I generated a dummy and count type variables for stunting, underweight, and wasting at the child level. In the case of the binary child nutrition status outcomes, the value 1 indicates stunting, underweight, and wasting and zero otherwise.

3.4. Control Variables

As in many developing countries, farm households in Uganda act as both producers and consumers of own production. In other words, choices regarding production (including technologies/practices to use for production) and consumption decisions are non-separable. Moreover, farmers face incomplete markets and act as utility maximizers (de Janvry, Fafchamps and Sadoulet, 1991), as opposed to profit maximizers. Hence a non-separable household model is ideal in the context of Uganda. In addition, adoption of legume-based cropping is correlated to production, consumption, and market-related variables. In the study by Manda et al. (2017) age of household head, land ownership, and education of household head are among the main factors that affect adoption decisions, and therefore I included them as control variables. The succeeding paragraphs discuss the details of production, consumption and market-related variables included in my models.

Production-related control variables include (1) plot level characteristics such as the total number of plots owned, total area planted/owned; (2) household-level characteristics affecting

[12]"Z-score (or SD-score) = (observed value - median value of the reference population)/standard deviation value of reference population" (Source; http://www.who.int/nutgrowthdb/about/introduction/en/index4.html

production include total value of household assets, total livestock units[13], other sources of income, distance to the roads, distance to the market; (3) district-level variables such as prices of main crops like beans, maize, and groundnut right before planting season. As farmers planting decisions primary depend on the crops before the planting season, I took the previous year and last season prices in each of survey rounds. Also, household-related characteristics that affect both production and consumption include age, gender and educational level of the household head, and household size.

Community-level variables include average temperatures and annual rainfall. To account for the impact of access to agricultural and market information, I include a dummy variable equal to one for radio or mobile ownership or equal to zero for those who do not own. A year dummy was included to account for time differences across the four survey rounds. To further differentiate how legume-based cropping affect households who reside predominantly in rural or a peri-urban setting, I included a dummy variable equal to one for 'urban' and zero for rural, and its interaction with each of the legume-based cropping. To take account of time and location-specific variability, I included an interaction term for region and year.

For the child nutrition status outcome analysis, I included many of the (i) household-level variables listed in earlier paragraph and additional variables such as number of children between ages 6 to 59 months; and (ii) child level variables such as age of child in months completed, gender of child taking the value 1 for male and 0 for female, and a dummy for diarrhea, taking the value 1 for a child having diarrhea two weeks before the survey period and 0 otherwise. Moreover, since nutrition status is closely linked with access to quality water, sanitation and hygiene (i.e., WASH indicators), I included (iii) WASH indicator variables that take a value of 1 if household has access to safe drinking water, flush toilet or ventilated improved covered pit latrines or zero otherwise. The study

[13] The total livestock owned by the household was converted in to common units using total livestock unit conversion factor for sub-Saharan Africa (Njuki et al. 2011).

further includes (iv) community-level variables namely, access to government-owned clinics and access to a market, both taking the value of one if the household has access, and 0 otherwise.

3.5. Empirical Strategy

As mentioned earlier, legume-based cropping is hypothesized to play a prominent role in the agriculture-food security-nutrition nexus. The fundamental objective of this study is to empirically test this hypothesis about whether and which legume-based cropping impacts food security (as measured by indicators reflecting food availability, access, and stability), and through which pathway—production or income. Whether and how a household integrates legumes in their cropping system is equivalent to a technology adoption decision.

Technology adoption is an endogenous choice that households make and farmers might self-select whether to adopt or not. Hence there are many other unobserved factors that might affect the adoption decision and the outcome variables as well, leading to potential endogeneity problems. To address that, the study looked for variables that could be potential instruments (i.e., proportion of households using each legume-based practice excluding the household under consideration, access to agricultural extension services, and rainfall data. Nonetheless the f test on each instrument based on the reduced form equation was not strong enough. Hence the study was not able to address the potential endogeneity problems.

As noted in Chapter 2, In the context of a non-separable household model, my empirical analysis focuses on estimating the impact of the five types of legume-based cropping/practices on production outcome variables (calorie and protein produced), agricultural income (gross/net crop income), consumption outcome variables (HDDS, MAHFP), and nutrition outcome variables (extent and prevalence of stunting, underweight and wasting). The treatment variables used include cereal-legume intercropping, cereal-legume rotation, legume non-cereal intercropping, legume non-cereal rotation and legume monocropping. I take a two-step approach in my empirical strategy to address my research questions. First, I examine the direct effects of different legume-based cropping on all the outcome variables, irrespective of where they fall along the agriculture-food security-nutrition impact pathway illustrated in Figure 2. In the second step[14], I try to assess the pathway (production, income, or both) through which consumption related outcomes are impacted by regressing consumption outcome variables on production and income outcome variables. Lastly, I also analyze if increased crop income and protein/calorie production have any effect in reducing the prevalence of or extent of stunting, underweight and wasting of children within each household (i.e., nutrition outcome). To correct for serial correlation and heteroscedasticity, I clustered the standard errors at household level. The details of each step are as described below.

3.5.1. Step 1: Impact of Legume-Based Cropping on Household Food Security and Child Nutrition Outcomes

In assessing the impact of different legume-based cropping on food security outcomes, due to high attrition rate in the case of using balanced panel, the study analysis was restricted to unbalanced panel, where attrition bias was not a problem. Even though there is a difference in data type, distribution of the outcome variables, and existing tradeoffs regarding efficiency and consistency among different panel data models, I used linear models such as Pooled Ordinary Least Squares (POLS) and Fixed Effect (FE) models as opposed to Correlated Random Effects (CRE) models, which can potentially create bias in the case of unbalanced panels.

I first start with the simple pooled ordinary least squares (POLS) regression model. The main drawback of POLS model is that it does not allow controlling for individual-specific and time-invariant unobserved heterogeneity. As argued earlier, legume technology adoption is an endogenous choice that can be influenced by many unobservable factors (e.g., inherent management ability, risk attitudes, health status, motivation, etc.) that can potentially also affect household welfare and

[14] Note that the realization of this step depends on the results of step 1. In other words, it is contingent upon finding significant effect in step 1 of treatments on the production and income outcomes.

nutrition outcomes. Thus, using POLS can potentially result in biased estimates. However, as the assumptions of POLS are less restrictive and weaker than any other panel data models, I report POLS regression results as preliminary results and for comparison and robustness check as well.

To control for time constant unobserved heterogeneity, the fixed effects model is ideal and widely used for panel data analysis. By allowing the un-observables to be correlated with observable covariates, it reduces the time invariant unobserved heterogeneity problem. Equation 1 below represents household level fixed effect model for the household level food security analysis.

$$\boldsymbol{F_{ht}} = \propto + \boldsymbol{L_{ht}}\,\boldsymbol{\beta_1} + \boldsymbol{X_{ht}}\boldsymbol{\beta_2} + \boldsymbol{D_t}\boldsymbol{\beta_3} + \delta_h + \varepsilon_{ht} \text{...........Eq. 1}$$

Where $\boldsymbol{F_{ht}}$ represents food security outcome variables for each household h, at time t, $\propto$ represents the constant term, $\boldsymbol{L_{ht}}$ denotes legume technology variables in discrete form (dummy) and continuous form. The discrete form of $\boldsymbol{L_{ht}}$ takes the value one and zero for adoption and non-adoption, respectively. While, the continuous form of $\boldsymbol{L_{ht}}$ represents area of land planted (acres) under each legume-based cropping for each household *h,* at time *t.* $\boldsymbol{X_{ht}}$ represents a set of household characteristics including total land size planted, number of plots, total value of household assets, total livestock units owned, a dummy for non-farm income and residence. It also includes a set of community and market information characteristics; a dummy variable for mobile and radio ownership, and average prices of the major crops from previous seasons. The household fixed effect, δ_h, year dummy $\boldsymbol{D_t}$, and the idiosyncratic errors ε_{ht} are among the major variables in the model. The coefficients of interest in this model are $\boldsymbol{\beta_1}$, reflecting the impact of each legume-based practice on the outcome variables. A positive and significant $\boldsymbol{\beta_1}$, implies a positive impact of legume-based cropping on food security outcome variables. For the child level nutrition outcomes analysis, the fixed effect model/Linear Probability Model (LPM) is as shown in Equation 2.

$$\boldsymbol{N_{cht}} = \propto + \boldsymbol{L_{ht}}\,\boldsymbol{\beta_1} + \boldsymbol{X_{ht}}\boldsymbol{\beta_2} + \boldsymbol{W_{Ct}} + \boldsymbol{D_t}\boldsymbol{\beta_3} + \delta_h + \varepsilon_{ht} \text{...........Eq. 2}$$

Where $\boldsymbol{N_{cht}}$ represents nutrition outcome for child c, in household h, and at a time t, (i.e., child nutrition outcomes are in both continuous vs dummy forms), $\propto$ represents the constant term, $\boldsymbol{L_{ht}}$ denotes legume technology variables in discrete form (dummy) and continuous form, $\boldsymbol{X_{ht}}$ represents a set of household characteristics, $\boldsymbol{W_{Ct}}$ represents a set of child level characteristics including age of a child, and a dummy for child gender and diarrhea. The δ_h, $\boldsymbol{D_t}$, and ε_{ht} represent the household fixed effect, year dummy and the idiosyncratic errors respectively. The coefficients of interest in this model are $\boldsymbol{\beta_1}$, reflecting the impact of each legume-based practice on the child level nutrition outcome variables. A negative and significant coefficient in $\boldsymbol{\beta_1}$, implies a positive association/impact of legume-based technologies on binary type child nutrition outcomes (1.e., stunting, underweight and wasting) and the reverse for the continuous type of child nutrition outcomes (i.e., HAZ, WAZ, and WHZ z-scores).

3.5.2. Step 2: Impact of Gross/Net Crop Income and Protein Produced on HDDS and MAHFP

As mentioned above the first step was to assess the impact of legume-based cropping on household welfare, but that does not tell the specific pathway through which the consumption level outcomes are impacted, since these outcomes are further down the impact pathway of the agriculture-food security linkages (see Figure 2). After regressions of production outcome variables on legume-based practices, if I observe a positive and significant coefficient on net crop income and calorie/protein per capita, then it represents a positive impact of legume-based cropping on production outcomes (the first node in the impact pathway), and it would warrant this second step, where I analyze whether the impact of legume-based cropping on production outcomes translates into consumption outcomes. This was done by regressing HDDS and MAHFP, which are the two indicators of food consumption related outcomes, on gross/net crop income and protein production[15]. In this step, a positive and significant coefficient estimates on any of the production outcomes would represent the specific pathway. This second step is crucial as it unpacks the heterogeneous effects (disaggregates each production outcome effect) on nutrition outcomes or the effects of other unobserved covariates that can potentially affect HDDS and MAHFP, aside from net crop income and protein produced.

3.5.3. Step 2: Impact of Gross/Net Crop Income and Protein Produced on the Prevalence and Extent of Stunting, Underweight, and Wasting

Another dimension that the study looked at was, examining whether legume-based cropping further improves malnutrition status of children (i.e., stunting, underweight, and wasting). In doing this, the study used dummy and continuous variables for stunting, underweight, and wasting. For continuous type dependent variables, I used POLS and FE models for the continuous type, and Linear Probability Model (LPM) for the dummy type dependent variables as these models as LPM with FE model control time invariant unobserved heterogeneity and requires fewer distributional assumptions. Similar to the second step on household food security analysis, this step is done by regressing child level nutrition outcomes on protein and gross/net crop income. A negative and significant coefficient on the protein and gross/crop income indicates positive correlation with the binary type child nutrition outcomes (i.e., negative association with the continuous type child nutrition outcomes), and pathway through which legume-based practices can potentially affect child level nutrition outcomes.

[15]Protein production was selected as treatment variable mainly due to more protein content available in legumes than calories. Also, with the high correlation between protein and calorie produced (0.87), it is not possible to use both as main treatment variables in a model.

CHAPTER 4. RESULTS AND DISCUSSION

In this chapter I first present the summary statistics and descriptive analysis of all the outcome, treatment, and control variables used in the analysis. Then I present the results of econometric analysis, and discuss the main findings related to the impact of legume-based cropping on the food security and nutrition outcomes.

4.1. Descriptive Analysis and Summary Statistics

Table 1 shows descriptive statistics of all the relevant variables included in the analysis. On average, a typical farming household in Uganda has a family size of six members, a land size of four acres, owns 3.5 plots, has total livestock units of 2, and a household head who is 48 years of age and has 5 years of education. The urban farming household comprises around 12%, while the rural households account for 88% of the sample.

Over the survey period, 69% of households had reported having other means of income outside farming, and the remaining 31% depend solely on agriculture for their livelihood. While 81-85% of households had access to agricultural extension and government-owned health services, 93% have access to a market for agricultural produce. Moreover, 56% and 69% of the households in the study reported to own mobile phones and radio, respectively. The average value of household assets that a typical household owns was around 14, 091 thousand Ugandan Shillings (UGX[16],). Based on 2009 price index, the average price per Kilogram (kg) of most commonly grown crops, namely beans, groundnuts, and wheat, was 982, 993 and 454 UGX, respectively. Note however, that this is a snapshot picture of an average price. There is a high variability in price between seasons, years, and locations, which is not captured here.

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[16] 1 USD =1937.7 (2009); 1 USD =2481.5 (2014)
Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Related to geographical information, Uganda has four agroecological zones namely Tropic-warm/humid, Tropic warm/sub-humid, Tropic-cool/sub-humid and Tropic-cool/humid with 54%, 3%, 13%, and 30% of the households living in each zone, respectively. The country has both bimodal and unimodal growing seasons. In the sample survey data, 69% and 31% of households have unimodal and bimodal growing seasons, respectively. The country has an annual mean rainfall of 1195 millimeters (mm) and a mean temperature of around 22 degree Celsius.

Table 1: Summary Statistics for Whole Sample and for the Final Year (2013/14)

Variable Name	Description	Mean	Std. Dev.	Mean	Std. Dev.
		All Years (N=6,489)		*2013/14 (N=1,118)*	
Household level Food Security Outcome Variables					
HDDS	Household Dietary Diversity Score (0-12)	7.52	2.19	8.27	1.90
MAHFP **NF**	Number of food secure months in a year (0-12)	10.91	2.02	11.38	1.44
Net crop income	Net crop income/day/HH (UGX,2009/10=100)	2672.38	3926.99	1981.88	2273.68
Gross crop income	Gross crop income/day/HH (UGX,2009/10=100)	2887.11	4032.72	2130.54	2327.55
Calorie per capita per day	Calorie produced per capita per day (Calories)	2258.02	3075.21	1669.53	1822.12
Protein per capita per day	Protein produced per capita per day (Grams)	65.45	91.60	52.41	60.51
Explanatory Variables OR Treatment Variables					
*Cereal-legume inter	=1 if the household adopt cereal-legume intercropping	0.52	0.50	0.51	0.50
*Cereal-legume rotation	=1 if the household rotate cereals and legumes	0.42	0.49	0.42	0.49
*Legume-non-cer-inter	=1 if the household adopt legume-non-cereal intercropping	0.50	0.50	0.46	0.50
*Legume-non-cer-rota	=1 if the household adopt legume-non-cereal rotation	0.60	0.49	0.54	0.50
*Legume Monocropping	=1 if the household adopt legume monocropping	0.47	0.50	0.46	0.50
*Cer-leg-intr area	Cereal-legume intercropped area per HH (Acres)	0.58	1.01	0.51	0.74
*Cereal-leg-rota	Cereal legume rotated area per HH (Acres)	0.68	1.22	0.61	0.97
*Legume-non-cer inter	Legume non-cereal rotate intercropped area per HH (Acres)	0.59	1.03	0.40	0.61
*Legume-non-cer-rot	Legume non-cereal rotated area per HH (Acres)	1.10	1.57	0.78	1.02
*Legume-mono-cropped	Legume mono-cropped area per HH (Acres)	0.43	0.88	0.44	0.83
Control Variables					
Household Size	Household size	6.11	2.95	6.28	2.99
Head Age	Age of household head	48.14	15.14	50.25	14.90
Head Gender	1= Male, 0 otherwise	0.71	0.45	0.69	0.46
Head Edu.	Education level household head (Years)	5.27	3.70	5.33	3.78
Total Area Planted	Total area planted (Acres)	4.79	4.64	4.05	3.39
No. of Plots	Number of plots per household	3.31	1.84	3.71	1.89
TLU	Total tropical livestock units owned	2.07	10.14	1.74	4.68
Household Assets	Total value of household assets ('000 UGX,2009/10=100)	14091.52	72389.53	5967.59	19752.66
Other Income	Yes=1, if the household earns income from other sources other than subsistence farming	0.69	0.46	0.41	0.49
Mobile Phone	Yes=1, if the household owns Mobile phone	0.56	0.50	0.70	0.46
Radio	Yes=1, if the household owns Radio	0.69	0.46	0.72	0.45

Table 1 (Cont'd)

Variable Name	Description	Mean	Std. De	Mean	Std. De
Groundnut Price	Previous season ave. groundnut price at district level (UGX/kg, 2009/10=100)	993.55	588.23	880.74	331.71
Beans Price	Previous season ave. beans price at district level (UGX/kg, 2009/10=100)	982.79	642.60	752.96	148.38
Maize Price	Previous season ave. maize price at district level (UGX/kg, 2009/10=100)	454.71	471.91	345.84	44.68
Urban	0= Rural, 1 Urban	0.12	0.32	0.14	0.35
Community Level Variables					
Gov't Clinic	Yes=1, if government clinic exists in the community	0.85	0.35	0.84	0.36
Agricultural Extension	Yes=1, if agricultural extension center exists	0.81	0.39	0.83	0.37
Market	Yes=1 if the household has access to market, 0 otherwise	0.93	0.26	0.96	0.18
Dist. to Road	HH distance to nearest major road (Kms)	8.42	7.43	8.85	7.67
Dist. to Market	HH distance to nearest market (Kms)	32.56	18.68	33.14	18.86
Geographical Variables					
Average Temp.	Annual mean temperature (°C * 10)	218.77	18.14	218.62	17.21
Annual Rainfall	12-month total rainfall (mm) in Jan-Dec	1195.61	173.87	1196.35	139.55
Subsample of households with children		*All Years (N= 3,490)*		*2013/14 (N= 344)*	
Child Level Nutrition Outcome Variables					
HAZ	Height for age z-score	-1.49	1.68	-1.32	1.67
WAZ	Weight for age z-score	-0.75	1.22	-0.60	1.27
WHZ	Weight for height z-score	0.13	1.33	0.27	1.66
Stunting	Yes=1, if the child HAZ z-score is <-2SD, 0 otherwise	0.35	0.48	0.31	0.46
Underweight	Yes=1, if the child WAZ z-score is <-2SD, 0 otherwise	0.12	0.33	0.08	0.26
Wasting	Yes=1, if the child WHZ z-score is <-2SD, 0 otherwise	0.04	0.19	0.02	0.13
Child age	Age of child (5- 60 months)	33.50	14.62	41.00	10.98
Child gender	=1 if the child gender is Male,0 if Female	0.49	0.50	0.43	0.50
Diarrhea	Yes=1, if any child has diarrhea during the past days	0.09	0.28	0.09	0.29
Number of Children	Number of children between ages 6 to 59 months/HH	1.78	0.75	1.73	0.86
Safe Drinking Water	Yes=1, if the household has a safe means to drinking water	0.69	0.46	0.63	0.48
VIP Flush Latrine	Yes=1, if the household has VIP or flush toilet	0.02	0.15	0.01	0.12
Covered Pit Latrine	Yes=1, if the household has covered pit toilet	0.75	0.44	0.72	0.45

Note: * represents the treatment variables. Whole sample (N=6,489). MAHFP ^{NF} (N=4,717). Subsample of households with children (N=3,490). Net/Gross crop income are expressed Uganda shillings per day (UGX). Calorie/Protein produced per capita per day are expressed in calorie/grams. (1 USD =1937.7 (2009); 1 USD =2481.5 (2014). Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html.

Source; Author's calculation based on LSMS-IAS data

The summary statistics related to child nutrition outcomes are from a subsample of households with children aged 6 to 59 months. From this sub sample, I took households with children in at least two rounds. Table 2, represents the summary statistics on stunting, underweight and wasting for children appearing in at least two rounds. Based on that, the percentage of stunted, underweight and wasted children is 31.1%, 7.7 % and 1.8 % during the last wave of the survey respectively. The prevalence of stunting, underweight and wasting has do not show much variation across the four survey rounds, although there is a slight downward trend in these indicators over the five years between the first survey round (2009) and the last (2013/14). This could potentially be due to the difference in proportion of children appearing in each wave, with the largest number of children in wave one and smallest in wave four (Table 2).

Table 2: Prevalence of Stunting, Underweight and Wasting for Subsample of Households With 6-59 Months Children

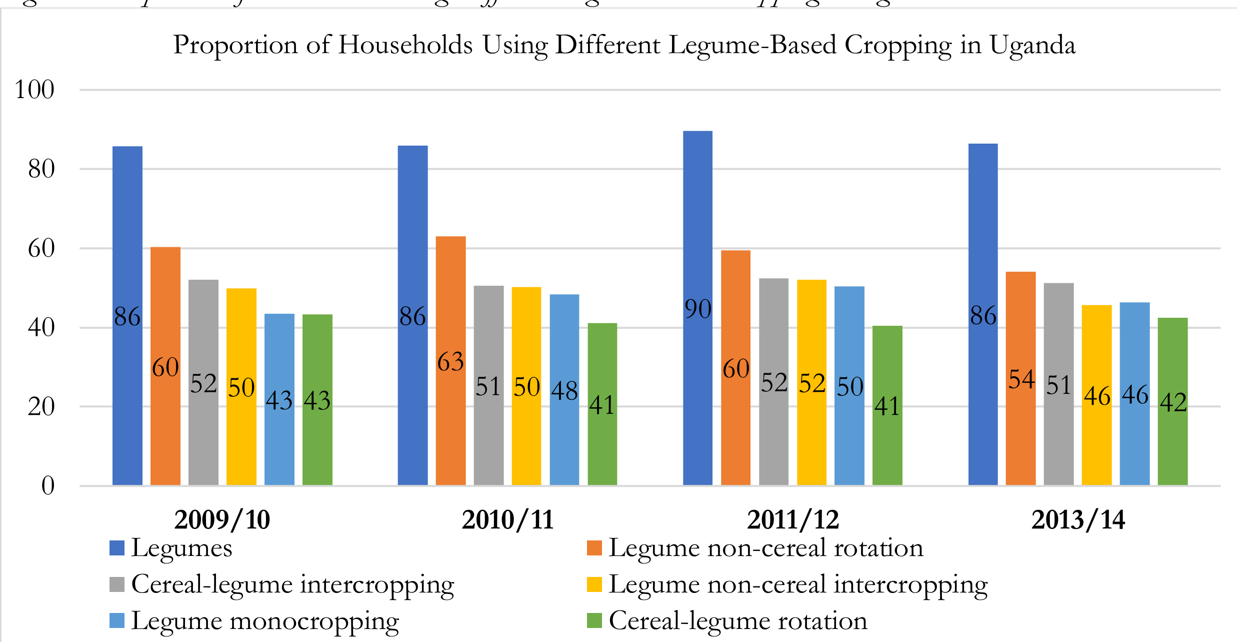
Child Nutrition Outcomes	**Proportion of children stunted, underweight and wasted at child and household level in each round**				
	2009/10	2010/11	2011/12	2013/14	Total Sum
Stunting	422(36.19%)	376(35.84%)	329(35.34%)	107(31.10%)	1234(35.36%)
Underweight	180 (15.44%)	120(11.44%)	103(11.06%)	26(7.56%)	429(12.29%)
Wasting	59(5.06%)	36(3.44%)	26(2.81 %)	6(1.75%)	127(3.64%)
No. of children	1166(33.41%)	1049(30.06%)	931(26.68%)	344(9.865)	3,490
No. of households	754(31.64%)	710(29.79%)	632(26.52%)	287(12.04%)	2,383

Note: Child level observations (N=3,490) on sub-sample of households with children (N=2,383) of four survey years (2009-2014). The value in parenthesis represent proportion of children.
Source; Author's calculation based on LSMS-IAS data

4.2. Importance of Different Legume-Based Cropping in the Ugandan Context

In Uganda, as shown in Figure 3, the proportion of households that grew legumes was in the range of 86-90% during the survey period. Among all legume-based cropping, (i.e., use of each legume-based cropping is not mutually exclusive and each household can adopt multiple practices at specific season or year). legume-noncereal- rotation was dominant followed by cereal-legume intercropping, legume-noncereal intercropping legume monocropping, and cereal-legume rotation in descending order of importance. The percentage of households rotating legumes with non-cereal crops was highest in 2010 (63%), followed by years 2009/10 and 2011/12 (60%), and 2013/14 (54%), while cereal-legume rotation prevalence was the smallest among all practices (41-43%. The proportion of households that intercrop legumes with cereals/noncereal remained indifferent ranging from 51 to 52% and that of legume monocropping households slightly varies among the survey years (50% in 2011/12 and 46% in 2013/14). Overall, there is not much difference in the overall proportion of households that integrate legumes in their cropping systems across the survey years, but the frequency of use of different practices varies from year to year (see Table 3).

Figure 3: Proportion of Households Using Different Legume-Based Cropping in Uganda



Note: Household level observations (N=6,489) of four survey years (2009-2014). Legume based cropping per each household are not mutually exclusive.

Source; Author's calculation based on LSMS-IAS data

As shown in Table 3 below, households practice legume-non-cereal rotation (10.9%) more sequentially than cereal-legume intercropping (10.6%), legume-non-cereal intercropping (9.8%) legume monocropping (8.4%), and cereal-legume rotation (4.1%), indicating a significant intra-household variation of technology adoption over the survey years. Similarly, the most adopted technology was legume-non-cereal rotation, while 25.1 % of the households did not rotate cereals and legumes within the survey period. These variability across time (years) supports using the household fixed effect model approach as an identification strategy to estimate the causal impacts legume-based cropping.

Table 3: Frequency of Legume-Based Cropping Adoption across the Four Survey Rounds.

Type of Technology	**Number of survey rounds in which a household reported using a given practice (out of total 4 rounds)**					
	0 None	**1 Round**	**2 Rounds**	**3 Rounds**	**4 Rounds**	**Total**
Legume- non-cereal rotation (%)	12.1	22.2	28.7	26.0	10.9	100
Cereal-legume intercropping (%)	20.9	22.1	24.4	22.1	10.6	100
Legume- non-cereal intercropping (%)	20.7	24.8	25.1	19.7	9.8	100
Legume mono-cropping (%)	21.5	26.5	24.8	18.8	8.4	100
Cereal-legume rotation (%)	25.1	31.0	25.8	14.1	4.1	100

Note: Household level observations (N=6,489) of four survey years (2009-2014).
Source; Author's calculation based on LSMS-IAS data

Before discussing the empirical results, I present the results of a two-tailed mean test for the main outcome variables with respect to users and non-users of each legume-based cropping. As shown in Table 4, mean comparisons (using t-test) of outcome indicators between users and non-users suggest that users of legume-based cropping are better-off in most of the food security outcome variables; households that used cereal-legume intercropping, cereal-legume rotation, legume monocropping, legume-non-cereal intercropping and legume-non-cereal rotation, report higher calorie and protein production, net crop income, HDDS, and MAHFP. Nonetheless the difference is weaker down the path; I did not find much difference on child nutrition outcome indicators between users and nonusers of each legume-based cropping.

Even though I found positive correlation between legume-based cropping and the outcomes related to food security, the test doesn't take the effect of other factors in to account and doesn't suggest causality. Hence the next section will explore further this issue of causality using econometric approaches.

Table 4: Comparison of Means of all Dependent Variables, among Users and Non-users of Different Legume-Based Cropping

Outcome Variables	**Cereal legume intercropping**			**Cereal legume rotation**			**Legume-non-cereal intercropping**			**Legume-non-cereal rotation**			**Legume monocropping**		
Adoption Decision	**No**	**Yes**	**P-val.**	**No**	**Yes**	**P-val.**	**No**	**Yes**	**P-val.**	**No**	**Yes**	**P-val.**	**No**	**Yes**	**P-val**
HDDS	7.3	7.7	***	7.5	7.6	**	7.4	7.6	**	7.4	7.6	***	7.5	7.5	--
MAHFP[F]	10.8	11.0	***	10.9	10.9	--	10.9	10.9	--	10.9	10.9	--	10.9	10.9	--
Net crop income	2426.9	2902.8	***	2496.7	2917.1	***	2344.5	3002.0	***	2088.5	3065.2	***	2268.9	3125.1	***
Gross crop income	2635.6	3123.2	***	2693.8	3156.4	***	2557.3	3218.7	***	2287.3	3290.7	***	2440.7	3388.0	***
Calorie per capita per day	2041.6	2461.2	***	2043.5	2556.7	***	2212.4	2303.8	--	2013.3	2422.7	***	1981.2	2568.6	***
Protein per capita per day	56.6	73.8	***	56.9	77.4	***	63.2	67.7	**	56.8	71.3	***	54.0	78.3	***
HAZ	-1.46	-1.53	--	-1.48	-1.51	--	-1.49	-1.50	--	-1.43	-1.54	**	-1.51	-1.47	--
WAZ	-0.74	-0.75	--	-0.76	-0.73	--	-0.75	-0.75	--	-0.72	-0.77	--	-0.79	-0.70	***
WHZ	0.11	0.15	--	0.10	0.18	*	0.12	0.14	--	0.12	0.14	--	0.09	0.19	**
Stunting	0.33	0.37	**	0.35	0.36	--	0.34	0.36	--	0.34	0.36	*	0.37	0.34	**
Underweight	0.12	0.13	--	0.12	0.13	--	0.12	0.13	--	0.12	0.12	--	0.14	0.11	***
Wasting	0.04	0.04	--	0.03	0.04	--	0.04	0.04	--	0.04	0.04	--	0.04	0.03	***

Notes: Yes= adoption and No=non-adoption of each legume-based cropping. P-Val. Indicates P value of mean test. Household level observations (N=6,489), MAHFP[F] observations (N=4,717), Child level observations (N=3,490) of four survey years (2009-2014). (***, **, *, and -- represents statistically significant at 1, 5 and 10% and nonsignificant values of a two-tailed test respectively). HDDS and MAHFP values range between 0 to 12. Net/Gross crop income are expressed in Uganda shillings per day (UGX). Calorie/Protein produced per capita per day are expressed in Calorie/grams. HAZ, WAZ and WHZ represent raw z-scores. Stunting, Underweight and Wasting takes either 1 or 0 values. (1 USD =1937.7 (2009); 1 USD =2481.5 (2014).
Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

4.3. Impact of Legume-Based Cropping on Household level Food Security and Child Level Nutrition Outcomes

To assess the impact of each of the legume-based cropping on food security and nutrition outcomes (household welfare), I applied all the regression models explained in Chapter 3 on the unbalanced household panel data (N=6,489). Tables 5 to 9 show the summary of regression results for each legume-based cropping with respect to each outcome variable. Each column in Tables 5 to 9 represents different estimators used. To capture the impact of the prevalence and extent of use of a given legume-based cropping, both binary and continuous treatment variables were used. The full regression results including the coefficients of all control variables are shown in Appendix B; Tables B 1-B 7. In this study, I used eight different outcome variables (representing different dimensions of food security), five main treatment variables (i.e., legume-based cropping), and a set of control variables. The POLS and fixed effect estimator coefficients are reported as average effects.

Before I discuss the main results of the model estimation for treatment variables (i.e., results in Tables 5-9), I briefly discuss the results related to the effect of control variables on the food security indicators reported in Tables B1-B 2 in Appendix B. Based on POLS regression results, among the main variables representing household characteristics, household size has a negatively significant effect on production outcome variables except for net crop income, reflecting the higher probability of food insecurity with increased family size. Gender of household head has significant effect on many of the outcome variables, indicating male-headed households are more productive and food secure than female-headed households in Uganda. This is consistent with the findings of Smith et al. (2006); with the exception of Mozambique, female-headed households were less productive in many SSA countries they studied, including Uganda. Both age and 'age squared' of household head remained insignificant in all of the outcome variables.

Similarly, education of household head has shown a positive and significant effect on many of the outcome variables while the impact of household head's 'education squared' remained insignificant, implying a nonlinear relationship. Not surprisingly, variables that represent assets owned by each household, namely total area planted, and number of plots owned has shown a positive and significant impact on many of production outcomes, indicating the positive contributions of asset ownership to enhancing food security. Non-farm assets like radio and mobile phone ownership, which is a proxy for both wealth and access to information, has a positive and significant effect on most of the outcome variables. Surprisingly, access to other forms of income, other than crop income, has remained insignificant on most of food security outcomes, except on HDDS. The results on HDDS suggest that households with non-farm sources of income are likely to have eaten more diverse types of foods in the past 7 days than households with no non-farm sources of income.

The variable 'urban' has a negative and significant impact on net crop income indicating, that those living in urban areas sell more crops than those living in rural areas, as they might have more access to markets. Moreover, the variable urban has shown positive and significant effect on MAHFP and HDDS, implying urban dwellers might have more access to food compared to rural dwellers. As far as the round (time) effect is concerned, I found a heterogenous effect of time (i.e., year) on many of the outcome variables indicating time have had an effect throughout the survey rounds. Region-wise, there was a negatively significant difference between Central and Eastern, but that of Northern and Western effect was dropped from the analysis. Turning now to the main results, I discuss the effects of each of the treatment variable on the outcome indicators.

4.4. Effects of Cereal-Legume Intercropping on Food Security and Nutrition Related Welfare Indicators

Due to the advantages of reaping multiple crops from the same plot in the same season, cereal-legume intercropping was may have a positively significant impact on food production, income, and nutrition outcomes. As reported in Table 5, I found positive and significant effect of cereal legume intercropping on calorie and protein produced, but effect is not robust across all estimators used. The effect remained insignificant on many of the food security and nutrition outcomes namely crop income, HDDS, and MAHFP, The POLS and FE regression results suggest that if a household adopts cereal-legume intercropping, on average it reaps additional 259-428 calories and 11-19 grams of protein per capita per day more than the household that do not practice cereal-legume intercropping, keeping all other factors constant (Table 5). Similarly, a houshold that alloted an additional acrea of land to cereal-legume intercropping, on average reaps 8 grams of addtiional protein per capita per day relative to nonusers, ceteris paribus. These results indicate that relative to the mean average on calorie/protein (2258 calories/65.4 grams of protein for all houeholds, the increase in calorie and protein approximates to about 15-18%/16-29% in the case of binary and continous treatment variables, respectively.

Even though, I expected positive impact of cereal legume intercropping on HDDS the results turned out to be insignificant. As a reminder, the HDDS indicator used in this study was estimated using 7-days recall period and not 24-hour recall. Hence, the longer time frame might have inflated the diversity score and thus resulted in biased estimates, as households are likely to consume and report more variety of foods in seven days than in 24 hours. A study by Kibrom and Qaim (2016) used seven days recall data for HDDS and found a significant impact of production diversity on that indicator in Uganda.

Turing to the analysis downstream in the agriculture-nutrition linkages pathway, the fixed effects results of cereal-legume intercropping on child nutrition outcomes has shown negative and significant impact of cereal-legume intercropping on HAZ z-score, indicating that an additional land allotted to cereal legume intercropping can potentially decrease a child's HAZ z-score by 0.058 points, keeping all other factors constant. Similarly, using POLS estimator the coefficient on underweight is negative and significant indicating that an additional land allotted to this practice reduce the probability of wasting by 0.57 percent, ceteris paribus. Compared to the mean average on

HAZ/wasting (-1.49/0.04), the effect of this practice on HAZ and wasting is not substantial (4% and 14% of the mean HAZ z-score and wasting). However given that the POLS does not account for unobserved heterogeneity bias, results based on POLS need to be interpretted with caution.

Overall, the effect of cereal-legume intercropping on food security indicators has shown little effect but remained insignificant in many of the outcome variables. The findings on this study are consistent with the findings by Sauer et al. (2016) for Zambia, where they also found little effect or insignificant effects of cereal-legume intercropping on cereal growing households.

Table 5: Main Regression Results related to the Effects of Cereal-Legume Intercropping on Household Level Food Security and Child Level Nutrition Outcomes

Treatment Variables	**Binary (=1 if HH intercrops cereals & legume crops)**		**Continuous (Total acres of cereal-legume intercropped)**	
Estimator	POLS Coef	FE Coef	POLS Coef	FE Coef
Outcome Variables				
Household Level Outcomes				
Calorie per capita per day (Calories)	**427.608*****	**258.881***	203.683	88.493
	(127.986)	(140.725)	(138.955)	(150.152)
Protein per capita per day (Grams)	**18.844*****	**11.091*****	**7.671****	2.034
	(3.973)	(3.435)	(3.556)	(3.778)
Gross crop income (UGX,2009/10=100)	7.391	128.099	-109.259	20.228
	(140.357)	(162.628)	(93.814)	(115.238)
Net crop income (UGX,2009/10=100)	11.117	121.871	-117.303	14.201
	(137.113)	(159.134)	(92.288)	(113.957)
HDDS	0.001	0.014	0.038	0.029
	(0.084)	(0.082)	(0.049)	(0.043)
MAHFP [NF]	0.031	0.090	-0.054	-0.023
	(0.073)	(0.101)	(0.045)	(0.055)
Child Level Outcomes				
HAZ (Height for age z-score)	-0.060	-0.035	-0.006	**-0.058***
	(0.072)	(0.074)	(0.036)	(0.034)
WAZ (Weight for age z-score)	-0.049	-0.017	0.004	-0.008
	(0.057)	(0.059)	(0.025)	(0.024)
WHZ (Weight for height z-score)	-0.008	0.022	0.005	0.029
	(0.063)	(0.078)	(0.029)	(0.027)
Stunting (HAZ z-score is <-2SD)	0.0328	0.0230	0.0060	0.0131
	(0.0215)	(0.0224)	(0.0101)	(0.0107)
Underweight (WAZ z-score is <-2SD)	0.0090	0.0012	-0.0067	-0.0016
	(0.0154)	(0.0162)	(0.0064)	(0.0065)
Wasting (WHZ z-score is <-2SD)	-0.0033	-0.0063	**-0.0057***	-0.0038
	(0.0078)	(0.0110)	(0.0032)	(0.0043)

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis); Household level observations (N=6,489), MAHFP[F] observations (N=4,717), Child level observations (N=3,490) of four survey years (2009-2014). POLS and FE standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. HDDS and MAHFP values range between 0 to 12. Net/Gross crop income are expressed in Uganda shillings per day (UGX). Calorie/Protein produced per capita per day are expressed in calories/grams. HAZ, WAZ and WHZ represent raw z-scores. Stunting, Underweight and Wasting takes either 1 or 0 values. (1 USD =1937.7 (2009); 1 USD =2481.5 (2014). Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

4.5. Effects of Cereal-Legume Rotation on Food Security and Nutrition Related Welfare Indicators

The presentation of regression results in Table 6 for cereal-legume rotation follows similar format as cereal-legume intercropping regression results, where each column represents the estimator used, and the rows represent the outcome variables. Overall, cereal-legume rotation results are weaker than cereal legume intercropping and remained insignificant on most of the outcome variables except on protein produced, WAZ and WHZ. But even for these few outcomes, results are not robust across all estimators used.

Results of the POLS model suggest that keeping all other factors constant, households that rotate legumes with cereals on average gain 8 grams of more protein per capita per day than the households that do not practice cereal-legume rotation; indicating an average increase of about 12% relative to the average protein production per day of 65 g in the sampled households. FE effect results suggest that one acre of land rotated with cereals and legume on average increases the WAZ and WHZ z-scores by 0.08 and 0.03 points, respectively, keeping all other factors constant. Nonetheless these results are not robust across all estimators and type of child nutrition outcome indicators and need to be interpreted with caution.

Overall, my analysis suggests little effect of cereal-legume rotation on the immediate food production indicators measured by protein produced per capita per day, and child nutrition outcomes namely WAZ and WHZ z-scores, but the effect remained insignificant on all other variables.

Table 6: Main Regression Results related to the Effects of Cereal-Legume Rotation on Household Level Food Security and Child Level Nutrition Outcomes

Treatment Variables	**Binary (=1 if HH rotates cereal & legume crops)**		**Continuous (Total acres of cereal legume rotated)**	
Estimator	POLS Coef	FE Coef	POLS Coef	FE Coef
Outcome Variables				
<u>Household Level Outcomes</u>				
Calorie per capita per day (Calories)	205.268	115.470	-4.583	-51.337
	(139.287)	(134.319)	(90.913)	(96.834)
Protein per capita per day (Grams)	**7.955***	5.026	1.050	-0.531
	(4.280)	(3.358)	(2.439)	(2.533)
Gross crop income (UGX,2009/10=100)	-145.913	-86.536	-42.793	-68.478
	(133.256)	(142.007)	(76.364)	(77.651)
Net crop income (UGX,2009/10=100)	-171.552	-115.746	-55.930	-84.871
	(131.684)	(140.461)	(75.582)	(77.151)
HDDS	0.077	0.047	0.012	-0.017
	(0.080)	(0.079)	(0.041)	(0.036)
MAHFP ^{NF}	-0.122	-0.151	0.008	-0.011
	(0.075)	(0.092)	(0.030)	(0.036)
<u>Child Level Outcomes</u>				
HAZ (Height for age z-score)	-0.016	0.030	0.005	-0.003
	(0.070)	(0.065)	(0.031)	(0.030)
WAZ (Weight for age z-score)	0.049	**0.076***	0.016	0.028
	(0.054)	(0.043)	(0.021)	(0.019)
WHZ (Weight for height z-score)	0.069	0.054	0.020	**0.034***
	(0.058)	(0.054)	(0.019)	(0.020)
Stunting (HAZ z-score is <-2SD)	-0.0004	-0.0129	-0.0022	-0.0016
	(0.0205)	(0.0215)	(0.0085)	(0.0081)
Underweight (WAZ z-score is <-2SD)	-0.0015	-0.0179	0.0027	-0.0031
	(0.0144)	(0.0138)	(0.0054)	(0.0054)
Wasting (WHZ z-score is <-2SD)	0.0074	0.0039	0.0026	-0.0011
	(0.0076)	(0.0090)	(0.0026)	(0.0037)

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis); Household level observations (N=6,489), MAHFP^{F} observations (N=4,717), Child level observations (N=3,490) of four survey years (2009-2014). POLS and FE standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. HDDS and MAHFP values range between 0 to 12. Net/Gross crop income are expressed in Uganda shillings per day (UGX). Calorie/Protein produced per capita per day are expressed in calories/grams. HAZ, WAZ and WHZ represent raw z-scores. Stunting, Underweight and Wasting takes either 1 or 0 values. (1 USD =1937.7 (2009); 1 USD =2481.5 (2014). Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

4.6. Effects of Legume-Noncereal Intercropping on Food Security and Nutrition Related Welfare Indicators

The summary of regression results on legume-non-cereal intercropping is presented in Table 7. As in previous tables, each column represents different estimators used. Unlike the results for cereal-legume intercropping and rotation, intercropping legumes with non-cereal crops has shown positive and significant ($p<.05$) effect for all categories of crop income, but sensitive to the type of treatment variable used. Based on the FE regression results for continuous treatment variables, an additional acre of land allotted to legume-non-cereal intercropping increases gross/net crop income by an average of 376/370 UGX per day, keeping the effects of all other factors constant. This effect is non-negligible (13%/14%) when compared to the daily gross/net crop income of 2887/2672 UGX. Nonetheless, the effect of legume non-cereal intercropping on gross/net crop income remained insignificant in the case of binary treatment variables. The study however did not find any effect of legume non-cereal intercropping on the remaining production outcome variables (calorie and protein produced).

Regarding consumption related outcomes, I found positive/negative and significant ($.05<P<.10$) effect of legume noncereal intercropping on HDDS/MAHFP but the effect is not robust across all models and types of treatment variables used. POLS result suggests that, if a household intercropped legumes and non-cereals, on average their 7-day HDDS increased by 0.18 points while MAHFP decreased by 0.14 points compared to non-users. The increment in HDDS and MAHFP is not significant in magnitude (2%/1%) compared to the mean average of 7.5 and 10.9 for both HDDS and MAHFP, respectively. The study, however, did not find any effect of legume non-cereal rotation practice on any of the child nutrition outcome variables.

Overall, the regression results have shown positive and significant effect on all categories of crop income and HDDS, but negative and significant effect on MAHFP. The effect remained insignificant for all other production outcomes (i.e. calorie and protein produced) and child level nutrition outcomes (i.e., stunting, underweight, and wasting).

Table 7: Main Regression Results related to the Effects of Legume-Noncereal Intercropping on Household level Food Security and Child Level Nutrition Outcomes

Treatment Variables	**Binary (=1 if HH intercrops legumes & non-cereal crops)**		**Continuous (Total acres of legume noncereal intercropping)**	
Estimator	POLS Coef	FE Coef	POLS Coef	FE Coef
Outcome Variables				
Household Level Outcomes				
Calorie per capita per day (Calories)	-124.542	-95.258	12.878	119.288
	(123.264)	(156.800)	(105.732)	(102.354)
Protein per capita per day (Grams)	-1.056	2.401	0.112	4.259*
	(3.524)	(4.212)	(2.463)	(2.188)
Gross crop income (UGX,2009/10=100)	145.984	189.330	**265.411****	**376.348****
	(148.693)	(181.522)	(108.410)	(153.515)
Net crop income (UGX,2009/10=100)	153.792	178.197	**272.268****	**370.481****
	(146.789)	(180.883)	(107.078)	(153.330)
HDDS	**0.182****	-0.084	0.069	-0.052
	(0.086)	(0.092)	(0.049)	(0.044)
MAHFP [NF]	**-0.137***	-0.148	-0.008	-0.025
	(0.077)	(0.115)	(0.043)	(0.055)
Child Level Outcomes				
HAZ (Height for age z-score)	0.101	0.119	-0.015	0.036
	(0.074)	(0.076)	(0.036)	(0.036)
WAZ (Weight for age z-score)	0.036	0.009	-0.029	-0.009
	(0.057)	(0.049)	(0.026)	(0.026)
WHZ (Weight for height z-score)	-0.013	-0.074	-0.024	-0.046
	(0.056)	(0.062)	(0.025)	(0.030)
Stunting (HAZ z-score is <-2SD)	-0.0032	-0.0040	0.0097	-0.0059
	(0.0216)	(0.0224)	(0.0107)	(0.0111)
Underweight (WAZ z-score is <-2SD)	0.0102	0.0144	-0.0005	0.0099
	(0.0152)	(0.0154)	(0.0033)	(0.0085)
Wasting (WHZ z-score is <-2SD)	0.0014	0.0015	-0.0005	0.0014
	(0.0079)	(0.0101)	(0.0033)	(0.0043)

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis); Household level observations (N=6,489), MAHFP[F] observations (N=4,717), Child level observations (N=3,490) of four survey years (2009-2014). POLS and FE standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. HDDS and MAHFP values range between 0 to 12. Net/Gross crop income are expressed in Uganda shillings per day (UGX). Calorie/Protein produced per capita per day are expressed in calories/grams. HAZ, WAZ and WHZ represent raw z-scores. Stunting, Underweight and Wasting takes either 1 or 0 values. (1 USD =1937.7 (2009); 1 USD =2481.5 (2014). Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

4.7. Effects of Legume-Non-Cereal Rotation on Food Security and Nutrition Related Welfare Indicators

The summary of the regression results (see Table 8) for legume non-cereal rotation on food security and nutrition outcomes follow the same format as that of cereal-legume cropping practices discussed in the previous sections. Compared to cereal-legume intercropping/rotation and legume non-cereal intercropping, the effect of legume-non-cereal rotation shows much stronger, positive and highly significant (0.01<p<0.10) effect on all production outcomes namely, calorie and protein produced, gross/net crop income and the effect is robust across all models and type of treatment variables used. For example, FE results suggest that for a household that rotates legume and non-cereal crops, on average calorie and protein produced per capita per day increases by 433 calories and 8 grams, respectively, while gross/net crop income increases by 306/290 UGX per household per day compared to non-users, ceteris paribus. The increment is not small in magnitude when compared to the mean average of calorie/protein per capita per day (2258 calories/65 grams) and gross/net crop incomes (2672/2887 UGX). Similarly, the FE results of the binary treatment variables suggest positive and significant effect on all the production outcomes with slightly smaller magnitude. The study, however, did not find any effect of legume non-cereal rotation on the two consumption related outcomes (i.e., HDDS and MAHFP).

Regarding the nutrition outcome indicators, surprisingly, relationship between legume non-cereal rotation and some of the nutritional outcomes is detrimental. For example, children belonging to households that practiced legume-non-cereal rotation had lower HAZ/WAZ z-scores than children belonging to households that did not practice legume-non-cereal rotation. Ceteris paribus, the POLS results suggest that if a household uses legume non-cereal rotation, the HAZ/WAZ z-score decreases by 0.17/0.10 units on average than relative to nonuser; indicating a substantial decline (14%/14%) in z scores (HAZ/WAZ) compared to the mean of each z score in the sample (-1.47/-0.75). Similarly, the FE model results suggest that a household practicing cereal-non-legume rotation has about 4% higher probability of children being stunted than non-practicing households. These negative effects on these nutritional outcomes are contrary to expectation and difficult to interpret.

The only positive result on nutritional outcome observed is the POLS result for continuous treatment variable, which suggests that for each additional acre of land allotted to this practice, the probability of a child being underweight declines by 0.0075 points; implying a small decline (6%) relative to the average value of underweight (0.12). This positive effect of legume-non-cereal rotation on child nutrition outcomes can potentially be due to the increases in income, calorie and protein production, where families may have access to enough food and diversified food.

Overall, the practice of rotating legumes with non-cereal crops have shown a positive and highly significant effect on all categories of crop income, calorie and protein produced by the practicing households and is robust across all models used. However, Legume non-cereal rotation has shown mixed effects on nutritional outcomes--negative and significant effect on HAZ, WAZ, and stunting, and positive and significant effect on reducing underweight. But none of these effects are robust across both estimators. Apart from production outcomes, the effect of legume noncereal rotation was not significant on the food consumption outcomes down the pathway (HDDS and MAHFP).

Table 8: Main Regression Results related to the Effects of Legume-Noncereal Rotation on Household Level Food Security and Child Level Nutrition Outcomes

Treatment Variables	**Binary (=1 if HH rotates legumes and non-cereal crops)**		**Continuous (Total acres of legume-noncereal-rotation)**	
Estimator	POLS Coef	FE Coef	POLS Coef	FE Coef
Outcome Variables				
<u>Household Level Outcomes</u>				
Calorie per capita per day	**305.219*****	**433.197*****	**238.649*****	**167.198*****
(Calories)	(112.525)	(148.153)	(56.640)	(60.202)
Protein per capita per day	**8.577****	**7.815****	7.713***	**3.501****
(Grams)	(3.522)	(3.806)	(1.797)	(1.602)
Gross crop income	**295.078****	**306.285***	**219.428*****	141.219
(UGX,2009/10=100)	(139.137)	(170.985)	(70.127)	(95.711)
Net crop income (	**289.770****	**290.123***	**214.521*****	139.593
UGX,2009/10=100)	(137.721)	(170.361)	(69.631)	(96.137)
HDDS	0.075	0.134	-0.028	0.018
	(0.085)	(0.091)	(0.035)	(0.031)
MAHFP ^{NF}	0.038	-0.101	0.001	-0.042
	(0.079)	(0.114)	(0.029)	(0.035)
<u>Child Level Outcomes</u>				
HAZ (Height for age z-score)	**-0.165****	**-0.158****	0.023	0.000
	(0.079)	(0.075)	(0.025)	(0.024)
WAZ (Weight for age z-score)	**-0.096***	-0.026	0.023	0.013
	(0.057)	(0.051)	(0.017)	(0.017)
WHZ (Weight for height z-	-0.012	0.092	0.015	0.022
score)	(0.058)	(0.060)	(0.016)	(0.019)
Stunting (HAZ z-score is <-2SD)	0.0291	**0.0400***	-0.0056	0.0019
	(0.0224)	(0.0229)	(0.0069)	(0.0064)
Underweight (WAZ z-score is	0.0029	-0.0059	**-0.0075***	-0.0056
<-2SD)	(0.0145)	(0.0146)	(0.0044)	(0.0048)
Wasting (WHZ z-score is <-2SD)	-0.0034	-0.0086	-0.0010	-0.0014
	(0.0080)	(0.0107)	(0.0020)	(0.0026)

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis); Household level observations (N=6,489), MAHFP^{F} observations (N=4,717), Child level observations (N=3,490) of four survey years (2009-2014). POLS and FE standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. HDDS and MAHFP values range between 0 to 12. Net/Gross crop income are expressed in Uganda shillings per day (UGX). Calorie/Protein produced per capita per day are expressed in calories/grams. HAZ, WAZ and WHZ represent raw z-scores. Stunting, Underweight and Wasting takes either 1 or 0 values. (1 USD =1937.7 (2009); 1 USD =2481.5 (2014). Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

4.8. Effects of Legume Monocropping on Food Security and Nutrition Related Welfare Indicators

Table 9 represents the summary of the regression results on the effect of legume monocropping on food security outcomes, where each column represents the estimator used. Based on the descriptives, among all legume technologies discussed above, legume monocropping practice is second least prevalent practice in Uganda followed by cereal-legume rotation. Nonetheless, the regression results of legume monocropping on food security outcomes turned out to be positive and significant for many of the production outcomes (i.e., gross income and protein produced), and child nutrition outcomes (i.e. WAZ Z-score, stunting and wasting). As shown in Table 9 the POLS regression results suggest that protein produced and gross income of legume monocropping household on average increased by 14 grams per capita per day and 207 UGX per household per day, respectively, ceteris paribus. But the result is non-robust across the FE models. The percentage increase in gross income and protein produced relative to the mean averages (2887 UGX/65 grams) is approximately 7% and 22% respectively; indicating the high protein content in legumes. This study didn't find any effect of legume mono-cropping on the consumption related outcomes.

As per the estimated coefficients on child nutrition outcomes, keeping all other factors constant, an additional acre of land allotted to legume monocropping reduces the probability of stunting and wasting by 0.017 and 0.009 percentage points and increases the WAZ Z score by 0.039 points. Relative to the mean average on stunting/wasting (0.35/0.04) the effect represents 5% reduction in the case of stunting and 23% reduction in the case of wasting. Overall, the regression results suggest positive and significant effect on production outcomes and on child nutrition outcomes. It indicates positive impact on WAZ z-score, and positive effect on reducing stunting and wasting with stronger effect on stunting; but the results remain non-robust across the models used, except for wasting (Table 9).

Table 9: Main Regression Results related to the Effects of Legume Monocropping on Household Level Food Security and Child Level Nutrition Outcomes

Treatment Variables	**Binary (=1 if HH adopts legume monocropping)**		**Continuous (Total acres of legume monocrop)**	
Estimator	POLS Coef	FE Coef	POLS Coef	FE Coef
Outcome Variables				
<u>Household Level Outcomes</u>				
Calorie per capita per day (Calories)	154.035	-71.364	55.558	-21.484
	(99.160)	(127.610)	(67.198)	(59.063)
Protein per capita per day (Grams)	**14.092*** **	5.765	**8.387*** **	2.780
	(2.991)	(3.664)	(2.536)	(2.699)
Gross crop income (UGX,2009/10=100)	**207.247***	39.131	65.700	14.400
	(115.364)	(148.003)	(86.451)	(93.621)
Net crop income (UGX,2009/10=100)	171.137	25.478	42.486	6.684
	(113.597)	(146.284)	(86.354)	(93.976)
HDDS	-0.121	0.089	-0.048	0.054
	(0.079)	(0.077)	(0.038)	(0.044)
MAHFP ^{NF}	-0.040	0.065	-0.013	0.063
	(0.071)	(0.094)	(0.036)	(0.043)
<u>Child Level Outcomes</u>				
HAZ (Height for age z-score)	0.079	0.041	0.021	-0.029
	(0.071)	(0.076)	(0.032)	(0.032)
WAZ (Weight for age z-score)	**0.098***	0.024	**0.039***	0.011
	(0.050)	(0.047)	(0.024)	(0.020)
WHZ (Weight for height z-score)	0.077	0.019	0.033	0.026
	(0.053)	(0.061)	(0.024)	(0.024)
Stunted (HAZ z-score is <-2SD)	**-0.0350***	0.0025	**-0.0168***	-0.0015
	(0.0206)	(0.0212)	(0.0094)	(0.0080)
Underweight (WAZ z-score is <-2SD)	-0.0193	0.0032	-0.0099	0.0023
	(0.0140)	(0.0151)	(0.0065)	(0.0062)
Wasted (WHZ z-score is <-2SD)	**-0.0127***	-0.0155	**-0.0085*** **	**-0.0071***
	(0.0070)	(0.0101)	(0.0030)	(0.0042)

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis); Household level observations (N=6,489), MAHFP^{F} observations (N=4,717), Child level observations (N=3,490) of four survey years (2009-2014). POLS and FE standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. HDDS and MAHFP values range between 0 to 12. Net/Gross crop income are expressed in Uganda shillings per day (UGX). Calorie/Protein produced per capita per day are expressed in calories/grams. HAZ, WAZ and WHZ represent raw z-scores. Stunting, Underweight and Wasting takes either 1 or 0 values. (1 USD =1937.7 (2009); 1 USD =2481.5 (2014). Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

4.9. Step 2: Effects of Gross/Net Crop Income and Protein Produced on HDDS and MAHFP

The results presented in sections 4.4 to 4.8 represent step 1 of the analysis, which indicates that some forms of integrating legumes with cereal or non-cereal crops either as rotation or intercropping or monocropping positively impacts production and income-related outcomes. As step 2, I now examine whether and how the positive impact of legume-based cropping translates from production-related outcomes to consumption related nutrition outcomes, and subsequently identify the pathways through which legume-based cropping affect nutritional status of farming households in Uganda. To assess this, I regress HDDS and MAHFP, which are the two indicators of food consumption related outcomes further down the impact pathway on net crop income and protein production[17].

Recall that due to the skewed distribution of net crop income, I incorporated both gross and net crop income as a robustness check. Moreover, due to the high correlation (0.87) between calorie and protein produced and higher protein content in legumes, I only include protein produced per household per day as a treatment variable as opposed to including both protein and calorie produced. In this step 2 of the analysis, I test if the effect of legume-based cropping on crop income and protein produced translates into the nutrition outcomes namely HDDS and MAHFP.

To test this hypothesis, I regressed consumption related outcome variables namely HDDS, a count variable that measures the quality of food consumed and MAHFP, measuring the quantity (and stability over time) of food consumed on net/gross crop income and protein produced per household per day. Also, due to the extremely small exchange rate of Ugandan shillings to dollars and for interpretation purposes, I converted the gross/net crop income per household per day into thousand Ugandan shillings, and grams of protein produced into hundred grams of protein

[17]Protein production was selected as treatment variable mainly due to more protein content available in legumes than calories. Also, with the high correlation between protein and calorie produced (0.87), it is not possible to use both as main treatment variables at the same time.

produced per household per day. The average gross/net crop income and protein produced per household per day was around 2.130/1.981 ('000 UGX) and 2.807 ('00 grams) respectively in the last wave (i.e. 2013/14) of the study.

Table 10 below shows the summary of regression results of HDDS and MAHFP on gross/net crop income and protein produced (see full regression results on Appendix B: Table B 4). The production and income related variables mentioned above serve as the main treatment variables, and all other variables as control variables. As shown in Table 10, the gross/net crop income has a positive and significant effect on MAHFP, while protein produced has a positive and significant effect on both HDDS and MAHFP. POLS model results suggest that as gross/net crop income per household per day increases by one thousand Ugandan shillings, MAHFP increases by 0.0212/.0208 points, respectively. Stated differently, given the exchange rate of 1 USD =1937.7 UGX, a dollar increases in gross crop income per day (which is roughly 2,000 UGX), increases MAHFP by 0.04 points. Similarly, keeping all other factors constant on average one hundred grams of increased protein produced per household per day increases MAHFP and HDDS by 0.03 and 0.02 points, respectively. Relative to the mean average of crop income and protein produced, the magnitude of the effect is small (2.1 UGX and 2.8 grams) per household per day, respectively.

As a robustness check and to detangle the heterogenous effect of all the production outcomes (likely high correlation between calorie and protein, and crop income). I also examined the individual effects of net crop income, calorie, and protein production on two consumption related outcomes. Table 11 shows the summary of regression results where each column represents consumption outcomes (i.e., HDDS and MAHFP) as a function of the main treatment variable in corresponding rows (i.e. net crop income, protein and calorie produced). The POLS regression results suggest positive and significant effect of production outcomes on HDDS and MAHFP, but the effect is not robust across FE model (i.e. the effect of protein produced and income remained insignificant in the case of HDDS). Hence, the take away message is that individually each of the production outcome variables are correlated to consumption related outcomes (Table 11).

In terms of the effect of other control variables included in the model, household size household head education, other sources of income, and urban vs. rural location variables have shown to be positively associated with HDDS implying households with more educated head, those that live in urban areas, and have other sources of income consume more diversified diets. I found negative and significant effect of all the regional dummies (Eastern, Northern, and Western) compared to Central region, indicating that households in the central region are more likely to have more access to diversified food compared to other regions of the country.

Overall, gross/net crop income has shown positive and significant effect on MAHFP, but not on 7-day HDDS, while calorie/protein produced has positive effect on both MAHFP and 7-day HDDS. Hence though it is hard to talk about causal effects, results suggest a positive correlation between (i) household gross/net crop income and MAHFP on access and stability dimensions of food security outcomes, (ii) positive correlation between calorie/protein and consumption related outcomes namely MAHFP and HDDS. Hence, I conclude with caution that the effect of legume-based cropping on production outcomes may translate into higher HDDS and MAHFP through calorie/protein production and to higher MAHFP through increased crop income.

Table 10: Summary Regression Results for the Effects of Gross/Net Crop Income and Protein Produced on HDDS and MAHFP

Estimator	Pooled Ordinary Least Squares				Fixed Effect			
Outcome Variables	HDDS	MAHFP	HDDS	MAHFP	HDDS	MAHFP	HDDS	MAHFP
Gross crop income/HH/day	0.0057	**0.0212*** **			-0.0047	0.0190		
	(0.0093)	(0.0071)			(0.0091)	(0.0118)		
Net Crop income/HH/day			0.0016	**0.0208*** **			-0.0074	0.0195
			(0.0093)	(0.0071)			(0.0091)	(0.0118)
Protein produced /HH/day	**0.0267*** **	**0.0179***	**0.0286*** **	**0.0187***	**0.0138***	0.0049	**0.0148***	0.0048
	(0.0092)	(0.0101)	(0.0092)	(0.0100)	(0.0083)	(0.0144)	(0.0083)	(0.0143)

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis). N=6,489 except for MAHFP (N=4,717), Standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. Net/Gross crop income are expressed in thousand Uganda shillings ('000 UGX). Protein produced per household per day is expressed in hundred grams ('00 grams). (1 USD =1937.7 (2009); 1 USD =2481.5 (2014). Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

Table 11: Summary Regression Results for the Effects of Net crop Income, Calorie and Protein Produced on HDDS and MAHFP

Estimator	Pooled Ordinary Least Squares					
Outcome Variables	HDDS	HDDS	HDDS	MAHFP	MAHFP	MAHFP
Net Crop income /HH/day	**0.017** **			**0.031*** **		
	(0.009)			**(0.006)**		
Calorie produced /HH/day		**0.009*** **			**0.008*** **	
		(0.002)			**(0.002)**	
Protein produced /HH/day			**0.029*** **			**0.031*** **
			(0.008)			**(0.009)**
Estimator	**Fixed Effect**					
Net Crop income /HH/day	-0.001			**0.022** **		
	(0.008)			**(0.010)**		
Calorie produced /HH/day		**0.005** **			0.004	
		(0.002)			(0.003)	
Protein produced /HH/day			0.012			0.016
			(0.008)			(0.013)

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis). N=6,489 except for MAHFP (N=4,717). Standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. Gross/net crop income are expressed in thousand Uganda shillings ('000 UGX). Protein produced per household per day is expressed in hundred grams ('00 grams). (1 USD =1937.7 (2009); 1 USD =2481.5 (2014); Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

4.10. Step 2: Effects of Gross/Net crop Income and Protein Produced on Child Nutrition Outcomes

As part of the second step discussed above, I also tried to examine the effect of net crop income and protein production on child nutrition related outcomes further down the impact pathway, namely the prevalence and extent of stunting, underweight and wasting among children in households that have children between 6-59 months of age. These indicators are used as proxies for measuring the nutritional status of children in each household. I included the prevalence and extent of stunting as a measure of long-term malnutrition status indicator, underweight as a composite measure and wasting as a short-term malnutrition status indicator. I used both continuous (HAZ, WAZ, WHZ) and binary variables for three indicators, where the continuous variable represents the raw z-score of each child (and measures the extent of malnutrition), and the dummy variable takes the value one if the child is stunted/underweight/wasted, and zero otherwise (and measures the prevalence of malnutrition). As mentioned in chapter 3, I use child, household and community level variables as a control in all the models.

Table 12, shows the summary regression results on child nutrition status outcomes, namely stunting, underweight and wasting. The effect of production related outcomes on child nutrition outcomes remained insignificant in all cases of child nutrition outcomes, except in the case of wasting; both gross and net crop income has shown positive and significant effect on wasting. POLS coefficients indicate that an additional one thousand Ugandan shillings of gross/net crop income per household per day decreases the probability of wasting by 0.0014 points. Stated differently, an additional dollar of net crop income per household per day reduces the probability of wasting by 0.0027 percentage. Compared to the mean probability of a child being wasted of 0.04 for the whole sample of children, the coefficient on wasting takes a small portion (3.5%) of the mean; suggesting that an increase in gross/net crop income by one dollar a day, leads to more than 6.7% reduction in the probability of being a wasted child, keeping all other factors constant. Therefore, the finding suggests that an increase in gross/net crop income may reduce the probability of having wasted child in each household while the effect of protein produced does not show any effect either on the prevalence or extent of stunting, underweight or wasting (Table 12).

Apart from the effect of production outcome variables on child nutrition indicators, looking at the effect of the control variables adds more information to the analysis. Based on the FE results number of children (6 to 59 months) per household is shown to have a positive and significant effect on HAZ and negative and significant effect on the of wasting, meaning keeping all other factors constant, with increased number of children per household, HAZ- z-score and the probability wasting for each child increases. Age of the child included (i.e., child between 6-59 months) is shown to have a positive and significant effect on WHZ and probability of wasting; indicating that with increased age the WHZ z-score increases and probability of being wasted child declines, keeping all other factors constant. Child gender is shown to have negative and significant effect on wasting, indicating that the probability of wasting is higher for male children relative to females. Also, the WASH indicators namely safe drinking water and VI latrines has shown positive and significant effect on WAZ z-scores and probability of wasting, but he effect is not consistent with the binary child nutrition outcomes. Finally, compared to 2009, there was positive and significant effect on WAZ z-score and probability of stunting in the last wave of the survey (i.e., 2013/14); this is consistent with the summary descriptive statistics discussed in Table 3.

Table 12: Summary Results for the Effects of Gross/Net crop Income and Protein Produced on Child Level Nutrition Outcomes

	Continuous Child Nutrition outcomes (HAZ, WAZ and WHZ z-scores)					
Child Nutrition Outcomes	**HAZ**	**WAZ**	**WHZ**	**HAZ**	**WAZ**	**WHZ**
Estimator	**Pooled Ordinary Least Squares**					
Gross Crop income/HH/day	0.0072	0.0008	-0.0059			
	(0.0101)	(0.0069)	(0.0052)			
Net Crop income/HH/day				0.0058	-0.0005	-0.0064
				(0.0103)	(0.0070)	(0.0053)
Protein produced/HH/day	-0.0042	0.0010	0.0040	-0.0033	0.0016	0.0041
	(0.0092)	(0.0064)	(0.0056)	(0.0092)	(0.0064)	(0.0056)
Estimator	**Fixed Effect**					
Gross Crop income/HH/day	0.0028	-0.0001	-0.0048			
	(0.0084)	(0.0048)	(0.0058)			
Net Crop income/HH/day				0.0036	0.0002	-0.0048
				(0.0086)	(0.0049)	(0.0059)
Protein produced/HH/day	-0.0088	0.0037	0.0069	-0.0092	0.0036	0.0068
	(0.0099)	(0.0045)	(0.0061)	(0.0099)	(0.0045)	(0.0061)
	Binary Child Nutrition outcomes (1, if z-scores below -2SD, 0 otherwise)					
Child Nutrition Outcomes	**Stunted**	**Underweight**	**Wasted**	**Stunted**	**Underweight**	**Wasted**
Estimator	**Pooled Ordinary Least Squares**					
Gross Crop income/HH/day	-0.0016	-0.0017	**-0.0014****			
	(0.0022)	(0.0016)	(0.0006)			
Net Crop income/HH/day				-0.0011	-0.0015	**-0.0014****
				(0.0023)	(0.0016)	(0.0006)
Protein produced/HH/day	0.0005	0.0006	0.0002	0.0002	0.0005	0.0002
	(0.0024)	(0.0017)	(0.0008)	(0.0024)	(0.0017)	(0.0008)
Estimator	**Fixed Effect**					
Gross Crop income/HH/day	-0.0003	0.0004	-0.0009			
	(0.0024)	(0.0014)	(0.0009)			
Net Crop income/HH/day				-0.0001	0.0005	-0.0009
				(0.0025)	(0.0014)	(0.0009)
Protein produced/HH/day	0.0013	-0.0008	-0.0011	0.0013	-0.0008	-0.0011
	(0.0027)	(0.0015)	(0.0012)	(0.0027)	(0.0015)	(0.0012)

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis). Child level observations (N=3,490) except for WHZ and Wasting(N=3,482). Standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. Gross/Net crop income per household per day is expressed in thousand Uganda shillings ('000 UGX). Protein produced per household per day is expressed in hundred grams ('00 grams). (1 USD =1937.7 (2009); 1 USD =2481.5 (2014); Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

Table 13: Summary Regression Results for the Effects of Net crop Income, Calorie and Protein Produced on Child Level Nutrition Outcomes

	Continuous Child Nutrition outcomes (HAZ, WAZ and WHZ z-scores)								
Child Nutrition Outcomes	**HAZ**			**WAZ**			**WHZ**		
Estimator	**Pooled Ordinary Least Squares**								
Net Crop income /HH/day	0.0038			0.0005			-0.0040		
	(0.0092)			(0.0057)			(0.0049)		
Calorie produced /HH/day		-0.0001			-0.0001			-0.0006	
		(0.0022)			(0.0013)			(0.0014)	
Protein produced /HH/day			-0.0004			0.0014			0.0009
			(0.0082)			(0.0051)			(0.0052)
Estimator	**Fixed Effect**								
Net Crop income /HH/day	-0.0006			0.0018			-0.0017		
	(0.0106)			(0.0044)			(0.0053)		
Calorie produced /HH/day		-0.0013			0.0005			0.0000	
		(0.0029)			(0.0011)			(0.0014)	
Protein produced /HH/day			-0.0077			0.0036			0.0050
			(0.0108)			(0.0040)			(0.0054)
	Binary Child Nutrition Outcomes (1, if z-scores is below -2 SD, 0 otherwise)								
Child Nutrition Outcomes	Stunted			Underweight			Wasted		
Estimator	**Pooled Ordinary Least Squares**								
Net Crop income /HH/day	-0.0010			**-0.0013*** **			-0.0012		
	(0.0020)			**(0.0005)**			(0.0012)		
Calorie produced /HH/day		-0.0005			-0.0002			-0.0002	
		(0.0005)			(0.0002)			(0.0004)	
Protein produced /HH/day			-0.0004			-0.0005			-0.0003
			(0.0021)			(0.0006)			(0.0013)
Estimator	**Fixed Effect**								
Net Crop income /HH/day	0.0005			**-0.0014***			0.0001		
	(0.0021)			**(0.0008)**			(0.0012)		
Calorie produced /HH/day		-0.0006			-0.0002			0.0000	
		(0.0007)			(0.0002)			(0.0004)	
Protein produced /HH/day			0.0012			-0.0014			-0.0006
			(0.0024)			(0.0010)			(0.0013)

Note: see footnote of Table 12. Source; Author's calculation based on LSMS-IAS data

CHAPTER 5. CONCLUSION

Food insecurity and malnutrition are some of the pressing problems facing countries in sub-Saharan Africa. Also, as the majority of the population depends on agriculture, agricultural transformation presumably is a key strategy to alleviate food insecurity. Nonetheless, despite increased efforts towards alleviating food insecurity, many countries, are far off from eradicating these problems. Sustainable farming practices like intercropping and rotation can potentially enhance soil/crop productivity, especially when integrated with legumes. Legumes are nutrient rich food crops grown in developing countries and integrating them within the farming systems can play a significant role in the agriculture-food security-nutrition nexus.

This study tried to look at the impact of legume-based practices on food security and nutrition outcomes of farming households in Uganda. To answer the main research questions, I used four waves of data on LSMS-IAS for Uganda. The study included nine outcome variables related to production, consumption and nutrition outcomes along the agriculture-food security-nutrition pathway, five treatment variables, and a set of household, child and community level variables as a control to the effects of other factors on the food security and nutrition outcomes. The empirical strategy was based on a non-separable household model, mainly due to the non-separability of production and consumption decisions of farming households in Uganda. I used different estimators; POLS, FE and LPM models to estimate the treatment effects.

Based on the summary statistics, among all legume growing households, legume non-cereal rotation and cereal-legume rotation were the most and least used practices, respectively, with significant difference in frequency of adoption among the survey years. Moreover, the prevalence of stunting, underweight and wasting was 35.36%, 12.29%, and 3.64 % respectively, with slight variation in the prevalence throughout the survey rounds.

The first step of the empirical findings showed a positive and significant effect of legume-based cropping on production outcomes (calorie, protein and gross/net crop income); In particular, I found strong effect of legume-non-cereal rotation on all production outcomes, strong effect of cereal-legume intercropping on both gross and net crop income, while the effect of monocropping and cereal legume rotation was positive in the case of protein production. Nonetheless, among downstream indicators along the pathway (i.e., consumption related outcomes), the effect of these practices was not significant for MAHFP. However, in the case of weekly HDDS, I found positive and significant effect of legume-non-cereal intercropping.

Even though I found positive and significant effect of these practices in production outcomes, there is little evidence or mixed evidence on their effects downstream on consumption related outcomes and child nutrition outcomes. One reason could be that there are potentially weak direct effects as we go downward the pathway (production to consumption to nutritional outcomes). Moreover, the 7 day' recall time frame for calculating HDDS indicator might have potentially reduced variability and resulted in biased estimates of this effect as household's consumption diversity is higher over a seven-day period as opposed to diversity in the past one day. In the case of MAHFP, the effect was insignificant probably due to the focus of this analysis on households that produced crops in two seasons, which potentially reduces the number of lean months due to two harvests over the 12-month period. The long time period between harvests and when the MAHFP data was collected can also be one of the reasons for not able to detect any significant effect on this indicator of food security (Sauer et al 2016).

For the child nutrition outcomes, the effect of these practices remained insignificant or inconclusive in most of the child level nutrition outcomes; I found mixed results with respect to the effects of cereal legume intercropping/rotation and legume-non-cereal rotation, and no significant effect of legume-non-cereal intercropping on child level nutritional outcomes. The only positive results were with respect to legume mono-cropping, where the results indicate that children belonging to households that practiced legume mono-cropping enjoyed higher WAZ, and lower probability of being stunted and wasted, which may potentially be due to the nutritional benefits of legume crops.

The second step of the analysis suggests a positive correlation of crop income on MAHFP, indicating that crop income is a potential pathway to increased MAHFP. Calorie and protein produced has shown positive correlation with both HDDS and MAHFP, suggesting that calorie and protein production are the pathways to increased food diversity and food security. Regarding the child nutrition outcomes, I found a positive correlation between crop income and wasting, suggesting that increased income may probably reduce the probably of wasting (short term effect).

In conclusion, the overall study results have shown positive effects on production and food access dimension of food and may provide support to the strategy of promoting the integration of legumes in the cropping systems of smallholder agriculture. At least, in the context of Uganda, the research and extension programs should promote studies that clearly address the integration of legumes in mixed cropping system.

The main challenge in this study was that it did not make distinction between the types of crops rotated/intercropped as different ways of integrating legumes in a cropping system have different impact. Hence it is important to narrow the analysis with respect to specific crop and practice. Moreover, due to data unavailability, this study was unable to capture the impact on women empowerment on food security indicator, which may potentially have a correlation to child nutrition outcomes. Finally, due to lack of strong instrumental variables the study is unable to suggest strong causal effects of legume-based cropping and results need to be interpreted with caution.

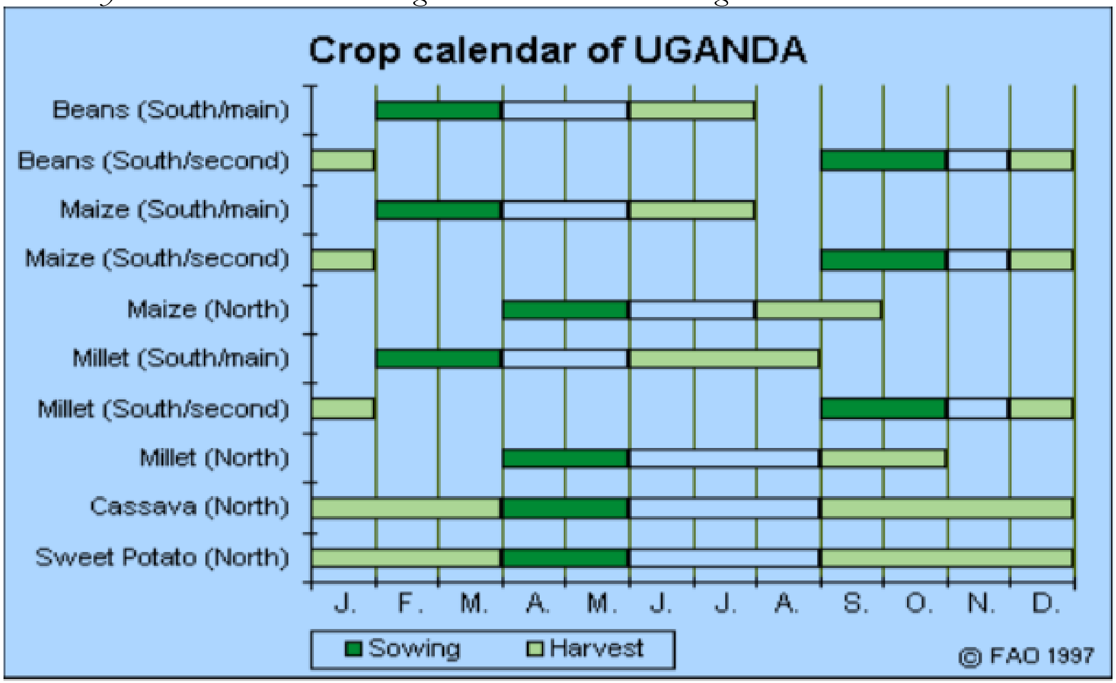
APPENDICES

Appendix A: General Information on Legume Crops, Seasonality and Data Cleaning

Figure A 1: Examples of Different Types of Legume Crops

Source;https://www.google.com/search?q=legumes+in+uganda&client=safari&channel=mac_bm&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwjJ_b6Hz4TcAhUJ6oMKHXxyDk4QsAQIbw&biw=1194&bih=758#imgrc=zL9XOI2-NagikM

Figure A 2: Yearly Calendar related to Planting and Harvest Months in Uganda



Source ; FAO, (2010)

Table A 1: Summary on Panel data Formation and Data Cleaning

Round	Interview Type	No. of HH's interviewed	Interview result		Final No. of HHs	Completely interviewed households in both questionnair (agriculture and household)	Children Interviewed
			Completed	Partially done			
2009/10	General Household	2,975	2,930	45	2,929		
	Agriculture	2,428			2,349	2,329	1,738
2010/11	General Household	2,716	2,657	59	2,657		
	Agriculture	2,208			2,135	2,094	1,368
2011/12	General Household	2,850	2,788	62	2,830		
	Agriculture	2,277			2,250	2,159	1,312
2013/14	General Household	3,119	3,118	1	3,119		
	Agriculture	2,495			2,437	2,437	1,717
	Rotated in 2013/14	1017 (32.61%)					
	Covered in wave 2011/12	2102 (67.39%)					
Overall	Unbalanced Panel (A)					9,019	
	Unbalanced Panel (B)					6,489	3, 490

Note: The Unbalanced panel(A) includes households that have two growing seasons and appeared in at least two rounds of the survey (N= 6,489). The Unbalanced panel (B) represents household that have child, grew crops in two seasons and appeared in at least two rounds of the survey(N=3,490)

Source; Author's calculation based on LSMS-IAS data (2009/10,2010/11, 2011/12, and 2013/14 waves

Appendix B: Full Regression Results

Table B 1: Fixed Effect Regression Results for the Effects of Legume-Based Cropping on Household Food Security Outcomes

Treatment Variables	**Binary (=1 if household adopts legume-based cropping)**					**Continuous (Total acres under use of each legume-based cropping)**				
Outcome Variables	HDDS	MAHFP	Net crop income	Calorie per capita per day	Protein per capita per day	HDDS	MAHFP	Net crop income	Calorie per capita per day	Protein per capita per day
Cereal - legume	0.014	0.090	121.87	**258.88***	**11.09*****	0.029	-0.023	14.20	88.49	2.03
intercropping	(0.08)	(0.10)	(159.13)	(140.72)	(3.43)	(0.04)	(0.05)	(113.96)	(150.15)	(3.78)
Cereal - legume	0.047	-0.151	-115.75	115.47	5.03	-0.017	-0.011	-84.87	-51.34	-0.53
rotation	(0.08)	(0.09)	(140.46)	(134.32)	(3.36)	(0.04)	(0.04)	(77.15)	(96.83)	(2.53)
Legume-non-cer-inter	-0.084	-0.148	178.20	-95.26	2.40	-0.052	-0.025	**370.48****	119.29	**4.26***
	(0.09)	(0.11)	(180.88)	(156.80)	(4.21)	(0.04)	(0.06)	(153.33)	(102.35)	(2.19)
Legume-non-cer_rot	0.134	-0.101	**290.12***	**433.20*****	**7.82****	0.018	-0.042	139.59	**167.20*****	**3.50****
	(0.09)	(0.11)	**(170.36)**	**(148.15)**	**(3.81)**	(0.03)	(0.03)	(96.14)	(60.20)	(1.60)
Legume	0.089	0.065	25.48	-71.36	5.77	0.054	0.063	6.68	-21.48	2.78
monocropping	(0.08)	(0.09)	(146.28)	(127.61)	(3.66)	(0.04)	(0.04)	(93.98)	(59.06)	(2.70)
Household Size	0.033	-0.061***	147.01***	-329.33***	-10.35***	0.035	-0.064***	151.84***	-322.04***	-10.13***
	(0.03)	(0.02)	(56.17)	(55.92)	(1.59)	(0.03)	(0.02)	(55.61)	(55.24)	(1.58)
Head Gender	-0.199	-0.118	-6.61	-35.59	-3.12	-0.213	-0.111	26.83	-34.81	-3.48
	(0.23)	(0.17)	(240.54)	(196.66)	(6.15)	(0.23)	(0.17)	(241.98)	(199.44)	(6.22)
Head Age	-0.062	-0.017	28.70	-27.41	-1.09	-0.062	-0.015	32.88	-26.50	-1.11
	(0.04)	(0.03)	(51.42)	(52.24)	(1.25)	(0.04)	(0.03)	(50.07)	(53.67)	(1.28)
Head Age squared	0.001	0.000	0.01	0.37	0.01	0.001	0.000	-0.02	0.37	0.01
	(0.00)	(0.00)	(0.47)	(0.51)	(0.01)	(0.00)	(0.00)	(0.45)	(0.52)	(0.01)
Head Edu	0.069	0.016	33.94	-17.83	-1.98	0.069	0.011	42.92	-12.62	-1.92
Head Edu squared	-0.001	-0.002	-2.75	-1.53	0.12	-0.001	-0.002	-3.19	-1.62	0.12
	(0.00)	(0.00)	(5.96)	(3.75)	(0.14)	(0.00)	(0.00)	(5.87)	(3.63)	(0.13)
Total Area Planted	0.009	0.002	18.35	67.55***	1.84***	0.008	0.004	-7.24	48.32**	1.18*
	(0.01)	(0.01)	(47.21)	(23.04)	(0.66)	(0.01)	(0.01)	(51.28)	(21.89)	(0.69)
No. of Plots	0.040*	0.028	259.54***	181.22***	4.27***	0.042*	0.031	290.23***	197.29***	5.19***
	(0.02)	(0.03)	(52.09)	(38.02)	(1.01)	(0.02)	(0.02)	(47.09)	(39.07)	(1.08)
TLU	0.013	-0.002	4.42	13.56*	0.34*	0.013	-0.000	2.58	10.89	0.27
	(0.01)	(0.01)	(20.08)	(7.87)	(0.20)	(0.01)	(0.01)	(19.44)	(7.47)	(0.19)
Household Assets	-0.000	0.000	0.00	-0.00*	-0.00	-0.000	0.000	0.00	-0.00*	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Table B 1 (Cont'd)

Treatment Variables	**Binary (=1 if household adopts legume-based cropping)**					**Continuous (Total acres under use of each legume-based cropping)**				
Outcome Variables	HDDS	MAHFP	Net crop income	Calorie per capita per day	Protein per capita per day	HDDS	MAHFP	Net crop income	Calorie per capita per day	Protein per capita per day
Household Assets	-0.000	0.000	0.00	-0.00*	-0.00	-0.000	0.000	0.00	-0.00*	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Other Income	0.105	-0.011	116.62	61.17	2.50	0.099	-0.001	122.82	51.26	2.44
	(0.08)	(0.10)	(142.09)	(148.94)	(3.87)	(0.08)	(0.11)	(142.10)	(147.74)	(3.85)
Beans Price	0.000	0.000*	-0.01	-0.07	-0.00*	0.000	0.000*	0.02	-0.05	-0.00
	(0.00)	(0.00)	(0.15)	(0.06)	(0.00)	(0.00)	(0.00)	(0.15)	(0.06)	(0.00)
Maize Price	0.000	-0.000	-0.01	-0.08	0.00	0.000	-0.000	-0.01	-0.07	0.00
	(0.00)	(0.00)	(0.10)	(0.09)	(0.00)	(0.00)	(0.00)	(0.10)	(0.09)	(0.00)
Radio	0.386***	0.249**	-20.06	44.40	4.12	0.394***	0.258**	-21.32	62.42	4.70
	(0.10)	(0.11)	(148.36)	(131.31)	(3.26)	(0.10)	(0.11)	(145.09)	(132.74)	(3.26)
Mobile Phone	0.235**	0.055	-19.03	121.17	4.24	0.231**	0.054	-26.05	120.89	4.18
	(0.10)	(0.12)	(175.42)	(144.85)	(4.08)	(0.10)	(0.12)	(175.54)	(145.14)	(4.08)
Urban	0.224	0.293	184.46	697.71	19.74	0.234	0.294	156.91	666.46	19.64
	(0.20)	(0.18)	(242.36)	(487.90)	(12.69)	(0.20)	(0.18)	(242.65)	(484.23)	(12.52)
Eastern	3.545***	0.971***	801.74*	74.09	1.03	3.498***	1.097***	829.98*	119.85	2.08
	(0.36)	(0.31)	(442.48)	(597.96)	(15.85)	(0.36)	(0.30)	(426.81)	(607.14)	(15.77)
Northern	-	-	-	-	-	-	-	-	-	-
Western	-	-	-	-	-	-	-	-	-	-
Year 2010/11	-0.340**		71.14	51.15	-7.95	-0.314*		-27.44	9.06	-8.83
	(0.17)		(368.31)	(277.32)	(6.77)	(0.17)		(351.48)	(268.73)	(6.55)
Year 2011/12	0.347**	0.884***	714.31*	72.73	-5.12	0.367**	0.872***	653.85	50.07	-5.11
	(0.15)	(0.16)	(420.59)	(284.22)	(6.99)	(0.16)	(0.16)	(412.39)	(280.98)	(6.93)
Year 2013/14	1.055***	0.382**	-825.14*	-737.61***	-19.88**	1.062***	0.358**	-724.88*	-623.32**	-16.50*
	(0.17)	(0.18)	(421.78)	(273.56)	(8.83)	(0.17)	(0.18)	(414.21)	(272.55)	(8.68)
Region Vs Year interaction	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	6.485***	10.819***	-1,063.65	3,544.44***	116.32***	6.583***	10.684***	-1,303.37	3,551.72***	122.47***
	(0.91)	(0.65)	(1,514.62)	(1,301.68)	(32.58)	(0.90)	(0.66)	(1,480.92)	(1,320.16)	(33.43)

Table B 1 (Cont'd)

Treatment Variables	**Binary (=1 if household adopts legume-based cropping)**					**Continuous (Total acres under use of each legume-based cropping)**				
Outcome Variables	HDDS	MAHFP	Net crop income	Calorie per capita per day	Protein per capita per day	HDDS	MAHFP	Net crop income	Calorie per capita per day	Protein per capita per day
R-squared	0.095	0.105	0.070	0.091	0.098	0.095	0.103	0.087	0.098	0.099
Observations	6,489	4,717	6,489	6,489	6,489	6,489	4,717	6,489	6,489	6,489
Number of HHID	2,097	2,097	2,097	2,097	2,097	2,097	2,097	2,097	2,097	2,097

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis); Household level observations (N=6,489), MAHFP[F] observations (N=4,717) of four survey years (2009-2014). Hyphen (-) represents missing results (i.e. Multicollinearity). FE standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. HDDS and MAHFP values range between 0 to 12. Net/Gross crop income are expressed in Uganda shillings per household per day (UGX). Calorie/Protein produced per capita per day are expressed in calories/grams. (1 USD =1937.7 (2009); 1 USD =2481.5 (2014). Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

Table B 2: Fixed Effect Regression Results for the Effects of Legume-Based Cropping on Continuous Child Nutrition Outcomes

Treatment Variables	**Binary (=1 if household adopts legume-based cropping)**			**Continuous (Total acres under use of each legume-based cropping)**		
Child Nutrition Outcomes	HAZ	WAZ	WHZ	HAZ	WAZ	WHZ
Cereal - legume intercropping	-0.035	-0.017	0.022	**-0.058***	-0.008	0.029
	(0.074)	(0.059)	(0.078)	(0.034)	(0.024)	(0.027)
Cereal - legume rotation	0.030	**0.076***	0.054	-0.003	0.028	**0.034***
	(0.065)	(0.043)	(0.054)	(0.030)	(0.019)	(0.020)
Legume-non-cer-inter	0.119	0.009	-0.074	0.036	-0.009	-0.046
	(0.076)	(0.049)	(0.062)	(0.036)	(0.026)	(0.030)
Legume-non-cer_rot	**-0.158****	-0.026	0.092	0.000	0.013	0.022
	(0.075)	(0.051)	(0.060)	(0.024)	(0.017)	(0.019)
Legume monocropping	0.041	0.024	0.019	-0.029	0.011	0.026
	(0.076)	(0.047)	(0.061)	(0.032)	(0.020)	(0.024)
Child age	-0.010***	-0.004***	0.007***	-0.010***	-0.004***	0.007***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Diarrhea	-0.135	-0.217***	-0.253***	-0.145	-0.217***	-0.245***
	(0.111)	(0.073)	(0.092)	(0.111)	(0.074)	(0.092)
Child gender	-0.104	-0.019	0.023	-0.102	-0.020	0.021
	(0.080)	(0.064)	(0.070)	(0.080)	(0.064)	(0.070)
Household Size	-0.044	-0.018	0.013	-0.042	-0.020	0.009
	(0.031)	(0.018)	(0.022)	(0.030)	(0.019)	(0.022)
Number of Children	0.129**	0.050	-0.061	0.123**	0.050	-0.057
	(0.054)	(0.035)	(0.047)	(0.054)	(0.035)	(0.046)
Head Gender	0.102	0.230	0.244	0.106	0.234	0.247
	(0.156)	(0.234)	(0.333)	(0.154)	(0.229)	(0.327)
Head Edu	-0.016	0.044	0.097*	-0.012	0.047	0.097*
	(0.047)	(0.041)	(0.055)	(0.046)	(0.041)	(0.055)
Head Edu squared	0.003	-0.004	-0.009***	0.003	-0.004	-0.009***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)
Total Area Planted	0.005	0.006	0.004	0.008	0.004	0.001
	(0.008)	(0.005)	(0.007)	(0.009)	(0.005)	(0.007)
No. of Plots	-0.011	0.005	0.014	-0.010	0.008	0.017
	(0.018)	(0.013)	(0.016)	(0.018)	(0.013)	(0.015)
TLU	-0.001	0.001*	0.003**	-0.001	0.001*	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Household Assets	-0.000	0.000	0.000*	-0.000	0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Beans Price	-0.000	-0.000	0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Maize Price	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Radio	0.022	-0.067	-0.086	0.029	-0.074	-0.098
	(0.079)	(0.049)	(0.064)	(0.079)	(0.049)	(0.063)
Mobile Phone	-0.047	-0.101*	-0.121	-0.063	-0.101*	-0.109
	(0.083)	(0.061)	(0.077)	(0.083)	(0.061)	(0.076)

Table B 2 (Cont'd)

Treatment Variables	**Binary (=1 if household adopts legume-based cropping)**			**Continuous (Total acres under use of each legume-based cropping**		
Child Nutrition Outcomes	HAZ	WAZ	WHZ	HAZ	WAZ	WHZ
Other Income	0.036	0.059	0.065	0.035	0.058	0.065
	(0.073)	(0.046)	(0.059)	(0.074)	(0.046)	(0.059)
Urban	0.184	0.293*	0.239	0.151	0.298*	0.268
	(0.249)	(0.151)	(0.205)	(0.253)	(0.152)	(0.204)
Year 2010/11	-0.191	-0.025	0.056	-0.204*	-0.024	0.067
	(0.123)	(0.085)	(0.109)	(0.122)	(0.085)	(0.109)
Year 2011/12	-0.140	0.034	0.064	-0.159	0.027	0.071
	(0.167)	(0.101)	(0.119)	(0.168)	(0.102)	(0.121)
Year 2012/13	0.105	0.330**	0.281	0.124	0.338**	0.276
	(0.219)	(0.135)	(0.217)	(0.216)	(0.134)	(0.215)
Eastern	-1.590***	1.035***	2.420***	-1.604***	1.009***	2.402***
	(0.351)	(0.213)	(0.312)	(0.344)	(0.208)	(0.308)
Northern	-	-	-	-	-	-
Western	-	-	-	-	-	-
Region Vs Year Interaction	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.626*	-1.231***	-1.344***	-0.646**	-1.218***	-1.303***
	(0.331)	(0.335)	(0.463)	(0.326)	(0.329)	(0.454)
Observations	3,490	3,490	3,482	3,490	3,490	3,482
R-squared	0.022	0.024	0.039	0.022	0.024	0.041
Number of HHID	922	922	922	922	922	922

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis). N= 3,490 except for WHZ (N=3,482). FE standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. Hyphen (-) represents missing results (i.e. Multicollinearity). HAZ, WAZ and WHZ represent raw z-scores.

Source; Author's calculation based on LSMS-IAS data

Table B 3: Fixed Effect Regression Results for the Effects of Legume-Based Cropping on Binary Child Nutrition Outcomes

Treatment Variables	**Binary (=1 if household adopts legume-based cropping)**			**Continuous (Total acres under use of each legume-based cropping)**		
Child Nutrition Outcomes	Stunting	Underweight	Wasting	Stunting	Underweight	Wasting
Cereal - legume intercropping	0.0230	0.0012	-0.0063	0.0131	-0.0016	-0.0038
	(0.0224)	(0.0162)	(0.0110)	(0.0107)	(0.0065)	(0.0043)
Cereal - legume rotation	-0.0129	-0.0179	0.0039	-0.0016	-0.0031	-0.0011
	(0.0215)	(0.0138)	(0.0090)	(0.0081)	(0.0054)	(0.0037)
Legume-non-cer-inter	-0.0040	0.0144	0.0015	-0.0059	0.0099	0.0014
	(0.0224)	(0.0154)	(0.0101)	(0.0111)	(0.0085)	(0.0043)
Legume-non-cer_rot	**0.0400***	-0.0059	-0.0086	0.0019	-0.0056	-0.0014
	(0.0229)	(0.0146)	(0.0107)	(0.0064)	(0.0048)	(0.0026)
Legume monocropping	0.0025	0.0032	-0.0155	-0.0015	0.0023	**-0.0071***
	(0.0212)	(0.0151)	(0.0101)	(0.0080)	(0.0062)	(0.0042)
Child age	0.0008	-0.0007	-0.0021***	0.0008	-0.0007	-0.0021***
	(0.0006)	(0.0005)	(0.0003)	(0.0006)	(0.0005)	(0.0003)
Diarrhea	-0.0403	0.0344	0.0135	-0.0379	0.0348	0.0124
	(0.0337)	(0.0261)	(0.0195)	(0.0336)	(0.0261)	(0.0195)
Child gender	0.0404	0.0108	0.0213**	0.0403	0.0105	0.0221**
	(0.0251)	(0.0170)	(0.0092)	(0.0251)	(0.0171)	(0.0092)
Household Size	0.0104	0.0021	-0.0042	0.0109	0.0025	-0.0039
	(0.0075)	(0.0046)	(0.0030)	(0.0074)	(0.0047)	(0.0030)
Number of Children	-0.0236	-0.0036	0.0163**	-0.0223	-0.0036	0.0161**
	(0.0154)	(0.0117)	(0.0065)	(0.0154)	(0.0117)	(0.0065)
Head Gender	-0.0206	-0.0415	-0.0041	-0.0264	-0.0422	-0.0049
	(0.0515)	(0.0493)	(0.0293)	(0.0514)	(0.0485)	(0.0302)
Head Edu	0.0200	-0.0054	0.0001	0.0194	-0.0060	0.0005
	(0.0130)	(0.0117)	(0.0083)	(0.0130)	(0.0116)	(0.0083)
Head Edu squared	-0.0020**	0.0003	0.0001	-0.0020**	0.0003	0.0001
	(0.0009)	(0.0008)	(0.0005)	(0.0009)	(0.0008)	(0.0005)
Total Area Planted	-0.0045*	0.0008	0.0016	-0.0047*	0.0008	0.0022*
	(0.0025)	(0.0015)	(0.0011)	(0.0028)	(0.0017)	(0.0012)
No. of Plots	0.0085	-0.0035	-0.0034	0.0090	-0.0030	-0.0047*
	(0.0065)	(0.0041)	(0.0025)	(0.0063)	(0.0039)	(0.0025)
TLU	0.0003	0.0002	-0.0000	0.0003	0.0001	0.0000
	(0.0003)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0001)
Household Assets	0.0000	-0.0000*	-0.0000	0.0000	-0.0000*	-0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Beans Price	0.0000	0.0000	-0.0000	0.0000	0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Maize Price	0.0000	-0.0000	0.0000	0.0000	-0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Radio	-0.0250	-0.0041	-0.0055	-0.0240	-0.0029	-0.0045
	(0.0238)	(0.0167)	(0.0094)	(0.0238)	(0.0167)	(0.0092)
Mobile Phone	-0.0152	0.0170	0.0298**	-0.0119	0.0171	0.0287**
	(0.0260)	(0.0186)	(0.0130)	(0.0260)	(0.0187)	(0.0130)
Other Income	-0.0238	-0.0090	-0.0253**	-0.0223	-0.0078	-0.0263**
	(0.0209)	(0.0152)	(0.0107)	(0.0208)	(0.0152)	(0.0107)

Table B 3 (Cont'd)

Treatment Variables	**Binary (=1 if household adopts legume-based cropping)**			**Continuous (Total acres under use of each legume-based cropping)**		
Child Nutrition Outcomes	Stunted	Underweight	Wasting	Stunted	Underweight	Wasting
Other Income	-0.0238	-0.0090	-0.0253**	-0.0223	-0.0078	-0.0263**
	(0.0209)	(0.0152)	(0.0107)	(0.0208)	(0.0152)	(0.0107)
Urban	-0.0316	-0.0261	0.0144	-0.0282	-0.0275	0.0102
	(0.0765)	(0.0337)	(0.0192)	(0.0777)	(0.0342)	(0.0191)
Year 2010/11	0.0407	-0.0252	0.0056	0.0429	-0.0236	0.0031
	(0.0376)	(0.0292)	(0.0171)	(0.0379)	(0.0291)	(0.0174)
Year 2011/12	-0.0237	-0.0344	0.0318*	-0.0196	-0.0321	0.0296
	(0.0441)	(0.0278)	(0.0187)	(0.0442)	(0.0281)	(0.0189)
Year 2012/13	-0.1130**	-0.0547	0.0003	-0.1149**	-0.0560	0.0010
	(0.0571)	(0.0432)	(0.0191)	(0.0574)	(0.0432)	(0.0185)
Eastern	-0.1614	-0.3927***	-0.4063***	-0.1538	-0.3871***	-0.4041***
	(0.1062)	(0.0594)	(0.0355)	(0.1046)	(0.0571)	(0.0332)
Northern	-	-	-	-	-	-
Western	-	-	-	-	-	-
Region Vs Year Interaction	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.3308***	0.3396***	0.2384***	0.3507***	0.3348***	0.2307***
	(0.0911)	(0.0823)	(0.0478)	(0.0901)	(0.0803)	(0.0468)
Observations	3,490	3,490	3,482	3,490	3,490	3,482
R-squared	0.016	0.016	0.051	0.015	0.016	0.051
Number of HHID	922	922	922	922	922	922

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis). N= 3,490 except for WHZ and Wasting (N=3,482). Standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. Hyphen (-) represents missing results (i.e. Multicollinearity). Stunting, Underweight and Wasting takes either 1 or 0 values.
Source; Author's calculation based on LSMS-IAS data

Table B 4: FE and POLS Regression Results for the Effects of Gross/Net Crop Income and Protein Production on HDDS and MAHFP

Estimator	**Pooled Ordinary Least Squares**				**Fixed Effect**			
Outcome Variables	HDDS	MAHFP	HDDS	MAHFP	HDDS	MAHFP	HDDS	MAHFP
Gross crop income	0.0057	**0.0212*****			-0.0047	0.0190		
	(0.0093)	(0.0071)			(0.0091)	(0.0118)		
Net Crop income			0.0016	**0.0208*****			-0.0074	0.0195
			(0.0093)	(0.0071)			(0.0091)	(0.0118)
Protein produced	**0.0267*****	0.0179*	**0.0286*****	**0.0187***	**0.0138***	0.0049	**0.0148***	0.0048
/HH/day	(0.0092)	(0.0101)	(0.0092)	(0.0100)	(0.0083)	(0.0144)	(0.0083)	(0.0143)
Household Size	0.0545***	-0.0654***	0.0549***	-0.0653***	0.0374	-0.0654***	0.0377	-0.0655***
	(0.0182)	(0.0120)	(0.0182)	(0.0120)	(0.0258)	(0.0217)	(0.0259)	(0.0217)
Head Gender	-0.1996**	-0.1154	-0.1989**	-0.1153	-0.2122	-0.0879	-0.2124	-0.0873
	(0.0940)	(0.0769)	(0.0940)	(0.0769)	(0.2357)	(0.1734)	(0.2359)	(0.1734)
Head Age	0.0172	0.0030	0.0174	0.0031	-0.0591	-0.0155	-0.0590	-0.0154
	(0.0156)	(0.0129)	(0.0156)	(0.0129)	(0.0394)	(0.0283)	(0.0394)	(0.0283)
Head Age squared	-0.0002	-0.0001	-0.0002	-0.0001	0.0006	0.0001	0.0006	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0004)	(0.0003)	(0.0004)	(0.0003)
Head Edu	0.1221***	0.0094	0.1225***	0.0095	0.0758	0.0103	0.0760	0.0103
	(0.0294)	(0.0241)	(0.0294)	(0.0241)	(0.0526)	(0.0455)	(0.0526)	(0.0455)
Head Edu squared	-0.0033	0.0015	-0.0033	0.0015	-0.0016	-0.0017	-0.0016	-0.0018
	(0.0021)	(0.0016)	(0.0021)	(0.0016)	(0.0036)	(0.0031)	(0.0036)	(0.0031)
Total Area Planted	0.0287***	0.0221***	0.0292***	0.0224***	0.0127*	0.0049	0.0127*	0.0051
	(0.0082)	(0.0072)	(0.0082)	(0.0072)	(0.0076)	(0.0091)	(0.0076)	(0.0091)
Household Assets	0.0000*	0.0000	0.0000*	0.0000	-0.0000	0.0000	-0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
TLU	0.0044	0.0006	0.0044	0.0007	0.0131	-0.0015	0.0131	-0.0014
	(0.0040)	(0.0031)	(0.0040)	(0.0031)	(0.0089)	(0.0061)	(0.0088)	(0.0061)
Other Income	0.2385***	0.0789	0.2391***	0.0795	0.1033	-0.0068	0.1033	-0.0066
	(0.0785)	(0.0722)	(0.0785)	(0.0722)	(0.0807)	(0.1059)	(0.0806)	(0.1059)
Radio	0.5878***	0.2204***	0.5882***	0.2208***	0.3872***	0.2477**	0.3869***	0.2477**
	(0.0869)	(0.0756)	(0.0869)	(0.0756)	(0.1015)	(0.1115)	(0.1015)	(0.1114)
Mobile Phone	0.6043***	0.3294***	0.6054***	0.3306***	0.2362**	0.0448	0.2360**	0.0455
	(0.0839)	(0.0748)	(0.0839)	(0.0748)	(0.0980)	(0.1240)	(0.0980)	(0.1240)
Dist. to Market	0.0010	-0.0010	0.0011	-0.0010				
	(0.0023)	(0.0018)	(0.0023)	(0.0018)				

Table B 4 (Cont'd).

Estimator	Pooled Ordinary Least Squares				Fixed Effect			
Outcome Variables	HDDS	MAHFP	HDDS	MAHFP	HDDS	MAHFP	HDDS	MAHFP
Dist. to Road	-0.0092	0.0019	-0.0091	0.0019				
	(0.0061)	(0.0051)	(0.0061)	(0.0051)				
Urban	0.5148***	0.2480***	0.5138***	0.2486***	0.2112	0.2609	0.2116	0.2614
	(0.1419)	(0.0922)	(0.1418)	(0.0922)	(0.1973)	(0.1765)	(0.1972)	(0.1766)
Eastern	0.1320	-0.6095***	0.1310	-0.6087***	3.4492***	1.0132***	3.4501***	1.0127***
	(0.1543)	(0.1539)	(0.1543)	(0.1539)	(0.3540)	(0.2877)	(0.3540)	(0.2878)
Northern	-0.1634	-1.4438***	-0.1662	-1.4424***	-	-	-	-
	(0.1721)	(0.1754)	(0.1721)	(0.1754)				
Western	-1.3716***	-0.2401*	-1.3669***	-0.2389*	-	-	-	-
	(0.1498)	(0.1430)	(0.1497)	(0.1431)				
Year 2010/11*	-0.4570***		-0.4578***		-0.3592**		-0.3586**	
	(0.1677)		(0.1678)		(0.1606)		(0.1605)	
Year 2011/12	0.2884*	0.7131***	0.2915*	0.7125***	0.3880***	0.8137***	0.3904***	0.8127***
	(0.1531)	(0.1206)	(0.1531)	(0.1207)	(0.1499)	(0.1487)	(0.1499)	(0.1489)
Year 2013/14	0.9659***	0.3133*	0.9644***	0.3113*	1.0791***	0.3509**	1.0785***	0.3492**
	(0.1697)	(0.1820)	(0.1696)	(0.1820)	(0.1507)	(0.1631)	(0.1505)	(0.1630)
Region Vs Year interaction	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	5.6336***	10.8478***	5.6253***	10.8457***	6.6262***	10.8165***	6.6226***	10.8172***
	(0.4223)	(0.3179)	(0.4221)	(0.3177)	(0.8969)	(0.6456)	(0.8968)	(0.6454)
Observations	6,489	4,717	6,489	4,717	6,489	4,717	6,489	4,717
R-squared	0.237	0.135	0.237	0.135	0.092	0.100	0.092	0.100
Number of HHID	N/A	N/A	N/A	N/A	2,097	2,097	2,097	2,097

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis). N=6,489 except for MAHFP (N=4,717). Standard errors are clustered at household level and robust to serial correlation and heteroskedasticity; 2010/11* represents no data on MAHFP. Hyphen (-) represents missing results (i.e. Multicollinearity). Net/Gross crop income are expressed in thousand Uganda shillings ('000 UGX). Protein produced per household per day is expressed in hundred grams ('00 grams). (1 USD =1937.7 (2009); 1 USD =2481.5 (2014). Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

Table B 5: Fixed Effect Regression Results for the Effects of Net Crop Income, Calorie and Protein Production on HDDS and MAHFP

Estimator	**Fixed Effect**					
Outcome Variables	**HDDS**	**HDDS**	**HDDS**	**MAHFP**	**MAHFP**	**MAHFP**
Net Crop income /HH/day	-0.001 (0.008)			**0.022**** **(0.010)**		
Calorie produced /HH/day		**0.005**** **(0.002)**			0.004 (0.003)	
Protein produced /HH/day			0.012 (0.008)			0.016 (0.013)
Household Size	0.039	0.035	0.037	-0.065***	-0.063***	-0.064***
	(0.026)	(0.026)	(0.026)	(0.022)	(0.022)	(0.022)
Head Gender	-0.213	-0.212	-0.212	-0.089	-0.086	-0.084
	(0.235)	(0.235)	(0.236)	(0.173)	(0.174)	(0.173)
Head Age	-0.060	-0.060	-0.059	-0.016	-0.014	-0.014
	(0.039)	(0.040)	(0.039)	(0.028)	(0.028)	(0.028)
Head Age squared	0.001	0.001	0.001	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Head Edu	0.075	0.074	0.075	0.010	0.011	0.012
	(0.053)	(0.052)	(0.053)	(0.046)	(0.046)	(0.046)
Head Edu squared	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
Total Area Planted	0.014*	0.012	0.013*	0.005	0.005	0.004
	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)
Household Assets	-0.000	-0.000	-0.000	0.000	0.000*	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
TLU	0.013	0.013	0.013	-0.001	-0.002	-0.002
	(0.009)	(0.009)	(0.009)	(0.006)	(0.006)	(0.006)
Other Income	0.106	0.103	0.103	-0.005	-0.005	-0.007
	(0.081)	(0.081)	(0.081)	(0.106)	(0.106)	(0.106)
Radio	0.392***	0.389***	0.388***	0.249**	0.246**	0.244**
	(0.101)	(0.101)	(0.101)	(0.112)	(0.111)	(0.111)
Mobile Phone	0.238**	0.235**	0.236**	0.047	0.043	0.044
	(0.098)	(0.098)	(0.098)	(0.124)	(0.124)	(0.124)
Urban	0.213	0.208	0.211	0.264	0.264	0.262
	(0.198)	(0.198)	(0.197)	(0.177)	(0.177)	(0.176)
Eastern	3.448***	3.447***	3.447***	1.009***	1.023***	1.023***
	(0.354)	(0.354)	(0.354)	(0.288)	(0.288)	(0.288)
Northern	-	-	-	-	-	-
Western	-	-	-	-	-	-
Year 2010/11*	-0.357**	-0.368**	-0.359**			
	(0.161)	(0.161)	(0.161)			
Year 2011/12	0.397***	0.373**	0.384**	0.815***	0.823***	0.824***
	(0.150)	(0.149)	(0.149)	(0.150)	(0.150)	(0.149)
Year 2013/14	1.080***	1.083***	1.082***	0.350**	0.340**	0.340**
Region Vs Year interaction	Yes	Yes	Yes	Yes	Yes	Yes
Constant	6.656***	6.642***	6.632***	10.825***	10.783***	10.770***
	(0.897)	(0.900)	(0.896)	(0.644)	(0.643)	(0.642)
Observations	6,489	6,489	6,489	4,717	4,717	4,717

Table B 5 (Cont'd)

Estimator	**Fixed Effect**					
Outcome Variables	**HDDS**	**HDDS**	**HDDS**	**MAHFP**	**MAHFP**	**MAHFP**
R-squared	0.092	0.093	0.092	0.100	0.099	0.099
Number of HHID	2,097	2,097	2,097	2,097	2,097	2,097

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis). N=6,489 except for MAHFP (N=4,717). FE and POLS Standard errors are clustered at household level and robust to serial correlation and heteroskedasticity; 2010/11* represents no data on MAHFP. Hyphen (-) represents missing results (i.e. Multicollinearity). Gross/net crop income are expressed in thousand Uganda shillings ('000 UGX). Protein produced per household per day is expressed in hundred grams ('00 grams). (1 USD =1937.7 (2009); 1 USD =2481.5 (2014); Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

Table B 6: Fixed Effect Regression Results for the Effects of Gross/Net Crop Income and Protein Production on Continuous Child Nutrition Outcomes

Child Nutrition Outcomes	**Continuous Child Nutrition Outcomes (HAZ, WAZ and WHZ z-scores)**					
	HAZ	WAZ	WHZ	HAZ	WAZ	WHZ
Gross Crop income/HH/day	0.0028	-0.0001	-0.0048			
	(0.0084)	(0.0048)	(0.0058)			
Net Crop income/HH/day				0.0036	0.0002	-0.0048
				(0.0086)	(0.0049)	(0.0059)
Protein produced/HH/day	-0.0088	0.0037	0.0069	-0.0092	0.0036	0.0068
	(0.0099)	(0.0045)	(0.0061)	(0.0099)	(0.0045)	(0.0061)
Child age	-0.0100***	-0.0045***	0.0070***	-0.0100***	-0.0045***	0.0070***
	(0.0023)	(0.0016)	(0.0019)	(0.0023)	(0.0016)	(0.0019)
Diarrhea	-0.1469	-0.2242***	-0.2522***	-0.1469	-0.2242***	-0.2522***
	(0.1111)	(0.0733)	(0.0912)	(0.1111)	(0.0733)	(0.0912)
Child gender	-0.0998	-0.0127	0.0285	-0.0999	-0.0127	0.0284
	(0.0804)	(0.0641)	(0.0703)	(0.0804)	(0.0641)	(0.0703)
Household Size	-0.0478	-0.0240	0.0081	-0.0478	-0.0240	0.0081
	(0.0310)	(0.0185)	(0.0215)	(0.0310)	(0.0185)	(0.0215)
Number of Children	0.1244**	0.0517	-0.0581	0.1243**	0.0517	-0.0580
	(0.0533)	(0.0352)	(0.0484)	(0.0533)	(0.0352)	(0.0484)
Head Gender	0.1161	0.2372	0.2415	0.1162	0.2371	0.2412
	(0.1603)	(0.2245)	(0.3199)	(0.1603)	(0.2244)	(0.3199)
Head Edu	-0.0135	0.0386	0.0864	-0.0134	0.0386	0.0864
	(0.0459)	(0.0413)	(0.0557)	(0.0459)	(0.0413)	(0.0558)
Head Edu squared	0.0029	-0.0037	-0.0088**	0.0029	-0.0037	-0.0088**
	(0.0029)	(0.0024)	(0.0035)	(0.0029)	(0.0024)	(0.0035)
Other Income	0.0343	0.0587	0.0686	0.0342	0.0587	0.0685
	(0.0731)	(0.0454)	(0.0591)	(0.0731)	(0.0455)	(0.0591)
VIP Flush Latrine	0.0277	0.1530	0.1770	0.0268	0.1527	0.1768
	(0.2363)	(0.1412)	(0.1649)	(0.2363)	(0.1412)	(0.1649)
Covered Pit Latrine	-0.1968**	-0.1093*	-0.0081	-0.1966**	-0.1093*	-0.0082
	(0.0978)	(0.0647)	(0.0828)	(0.0978)	(0.0647)	(0.0829)
Safe Drinking Water	0.1552	0.1494**	0.0711	0.1553	0.1494**	0.0711
	(0.1009)	(0.0629)	(0.0842)	(0.1009)	(0.0629)	(0.0842)
Gov't Clinic	0.2623	0.0252	-0.1579	0.2631	0.0254	-0.1586
	(0.3410)	(0.2201)	(0.2185)	(0.3413)	(0.2202)	(0.2185)
Urban	0.2208	0.3291**	0.2629	0.2210	0.3291**	0.2624
	(0.2508)	(0.1581)	(0.2054)	(0.2508)	(0.1581)	(0.2054)
Eastern	-1.6612***	0.7920***	2.1614***	-1.6613***	0.7920***	2.1618***
	(0.3171)	(0.2014)	(0.2831)	(0.3171)	(0.2014)	(0.2832)
Northern	-	-	-	-	-	-
Western	-	-	-	-	-	-
Year 2010/11	-0.1474	-0.0273	0.0181	-0.1474	-0.0272	0.0185
	(0.1089)	(0.0756)	(0.0961)	(0.1089)	(0.0756)	(0.0962)
Year 2011/12	-0.1605	0.0100	0.0578	-0.1619	0.0095	0.0579
	(0.1539)	(0.0903)	(0.1170)	(0.1539)	(0.0903)	(0.1170)
Year 2012/13	0.1150	0.3420***	0.2752	0.1147	0.3420***	0.2758
	(0.2061)	(0.1234)	(0.2158)	(0.2062)	(0.1234)	(0.2159)

Table B 6 (Cont'd)

Child Nutrition Outcomes	**Continuous Child Nutrition Outcomes (HAZ, WAZ and WHZ z-scores)**					
	HAZ	WAZ	WHZ	HAZ	WAZ	WHZ
Region Vs Year Interaction	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.8050*	-1.1744***	-1.0789**	-0.8060*	-1.1748***	-1.0794**
	(0.4447)	(0.3901)	(0.4990)	(0.4446)	(0.3901)	(0.4991)
Observations	3,490	3,490	3,482	3,490	3,490	3,482
R-squared	0.023	0.023	0.036	0.023	0.023	0.036
Number of HHID	922	922	922	922	922	922

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis). N= 3,490 except for WHZ and Wasting(N=3,482). Standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. Hyphen (-) represents missing results (i.e. Multicollinearity). HAZ, WAZ and WHZ represent raw z-scores. Gross/net crop income per household per day is expressed in thousand Uganda shillings ('000 UGX). Protein produced per household per day is expressed in hundred grams ('00 grams). (1 USD =1937.7 (2009). 1 USD =2481.5 (2014); Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

Table B 7: Fixed Effect Regression Results for the Effects of Gross/Net Crop Income and Protein Production on Binary Child Nutrition Outcomes

Child Nutrition Outcomes	**Binary Child Nutrition Outcomes (1, if z-scores is below -2 SD, 0 otherwise)**					
	Stunting	Underweight	Wasting	Stunting	Underweight	Wasting
Gross Crop income/HH/day	-0.0003	0.0004	-0.0009			
	(0.0024)	(0.0014)	(0.0009)			
Net Crop income/HH/day				-0.0001	0.0005	-0.0009
				(0.0025)	(0.0014)	(0.0009)
Protein produced/HH/day	0.0013	-0.0008	-0.0011	0.0013	-0.0008	-0.0011
	(0.0027)	(0.0015)	(0.0012)	(0.0027)	(0.0015)	(0.0012)
Child age	0.0008	-0.0006	-0.0021***	0.0008	-0.0006	-0.0021***
	(0.0006)	(0.0005)	(0.0003)	(0.0006)	(0.0005)	(0.0003)
Diarrhea	-0.0360	0.0358	0.0139	-0.0360	0.0358	0.0139
	(0.0334)	(0.0258)	(0.0192)	(0.0334)	(0.0258)	(0.0192)
Child gender	0.0399	0.0099	0.0218**	0.0399	0.0099	0.0218**
	(0.0251)	(0.0170)	(0.0092)	(0.0251)	(0.0170)	(0.0092)
Household Size	0.0112	0.0030	-0.0040	0.0112	0.0030	-0.0040
	(0.0077)	(0.0046)	(0.0032)	(0.0077)	(0.0046)	(0.0032)
Number of Children	-0.0219	-0.0040	0.0147**	-0.0219	-0.0040	0.0147**
	(0.0154)	(0.0117)	(0.0064)	(0.0154)	(0.0117)	(0.0064)
Head Gender	-0.0329	-0.0381	-0.0048	-0.0329	-0.0380	-0.0048
	(0.0507)	(0.0480)	(0.0289)	(0.0507)	(0.0480)	(0.0289)
Head Edu	0.0187	-0.0049	-0.0001	0.0187	-0.0049	-0.0001
	(0.0131)	(0.0116)	(0.0082)	(0.0131)	(0.0116)	(0.0082)
Head Edu squared	-0.0020**	0.0002	0.0001	-0.0020**	0.0002	0.0001
	(0.0009)	(0.0008)	(0.0005)	(0.0009)	(0.0008)	(0.0005)
Other Income	-0.0204	-0.0096	-0.0269**	-0.0205	-0.0096	-0.0269**
	(0.0206)	(0.0150)	(0.0108)	(0.0206)	(0.0150)	(0.0108)
VIP Flush Latrine	0.0103	-0.0830**	-0.0089	0.0101	-0.0831**	-0.0090
	(0.0622)	(0.0375)	(0.0262)	(0.0623)	(0.0375)	(0.0262)
Covered Pit Latrine	0.0463*	-0.0116	-0.0044	0.0463*	-0.0116	-0.0044
	(0.0270)	(0.0200)	(0.0116)	(0.0270)	(0.0200)	(0.0116)
Safe Drinking Water	-0.0233	-0.0314	-0.0053	-0.0233	-0.0314	-0.0053
	(0.0299)	(0.0212)	(0.0164)	(0.0299)	(0.0212)	(0.0164)
Gov't Clinic	0.0080	-0.0037	0.0654*	0.0080	-0.0036	0.0653*
	(0.1087)	(0.0828)	(0.0359)	(0.1087)	(0.0828)	(0.0358)
Urban	-0.0358	-0.0362	0.0067	-0.0358	-0.0361	0.0067
	(0.0756)	(0.0337)	(0.0191)	(0.0756)	(0.0337)	(0.0191)
Eastern	-0.1869*	-0.3667***	-0.3706***	-0.1869*	-0.3667***	-0.3705***
	(0.0971)	(0.0528)	(0.0280)	(0.0971)	(0.0528)	(0.0280)
Northern	-	-	-	-	-	-
Western	-	-	-	-	-	-
Year 2010/11	0.0274	-0.0161	0.0053	0.0275	-0.0161	0.0054
	(0.0336)	(0.0262)	(0.0151)	(0.0335)	(0.0262)	(0.0151)
Year 2011/12	-0.0067	-0.0328	0.0252	-0.0069	-0.0328	0.0252
	(0.0389)	(0.0252)	(0.0182)	(0.0389)	(0.0252)	(0.0182)
Year 2012/13	-0.1050*	-0.0604	-0.0089	-0.1049*	-0.0604	-0.0088
	(0.0554)	(0.0405)	(0.0171)	(0.0554)	(0.0405)	(0.0171)

Table B 7 (Cont'd)

Child Nutrition Outcomes	**Binary Child Nutrition Outcomes (1, if z-scores is below -2 SD, 0 otherwise)**					
	Stunting	Underweight	Wasting	Stunting	Underweight	Wasting
Region Vs Year Interaction	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.3294**	0.3484***	0.1888***	0.3292**	0.3484***	0.1887***
	(0.1281)	(0.1065)	(0.0529)	(0.1281)	(0.1065)	(0.0529)
Observations	3,490	3,490	3,482	3,490	3,490	3,482
R-squared	0.013	0.016	0.047	0.013	0.016	0.047
Number of HHID	922	922	922	922	922	922

Note: (*** p<0.01, ** p<0.05, * p<0.1, robust standard errors are in parenthesis). N= 3,490 except for WHZ and Wasting (N=3,482). Standard errors are clustered at household level and robust to serial correlation and heteroskedasticity. Hyphen (-) represents missing results (i.e. Multicollinearity). Stunting, Underweight and Wasting takes either 1 or 0 values Gross/net crop income per household per day is expressed in thousand Uganda shillings ('000 UGX). Protein produced per household per day is expressed in hundred grams ('00 grams). (1 USD =1937.7 (2009); 1 USD =2481.5 (2014);

Source; https://www.calcprofi.com/exchange-rate-history-us-dollar-to-uganda-shilling.html

Source; Author's calculation based on LSMS-IAS data

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