Feed the Future Innovation Lab for Food Security Policy

Research Paper 36 December 2016

IMPACTS OF LEGUME TECHNOLOGIES ON FOOD SECURITY: EVIDENCE FROM ZAMBIA

By

Christine M. Sauer, Nicole M. Mason, Mywish K. Maredia and Rhoda Mofya-Mukaka

Food Security Policy ***Research Papers***

This *Research Paper* series is designed to timely disseminate research and policy analytical outputs generated by the USAID funded Feed the Future Innovation Lab for Food Security Policy (FSP) and its Associate Awards. The FSP project is managed by the Food Security Group (FSG) of the Department of Agricultural, Food, and Resource Economics (AFRE) at Michigan State University (MSU), and implemented in partnership with the International Food Policy Research Institute (IFPRI) and the University of Pretoria (UP). Together, the MSU-IFPRI-UP consortium works with governments, researchers and private sector stakeholders in Feed the Future focus countries in Africa and Asia to increase agricultural productivity, improve dietary diversity and build greater resilience to challenges like climate change that affect livelihoods.

The papers are aimed at researchers, policy makers, donor agencies, educators, and international development practitioners. Selected papers will be translated into French, Portuguese, or other languages.

Copies of all FSP Research Papers and Policy Briefs are freely downloadable in pdf format from the following Web site: www.foodsecuritylab.msu.edu

Copies of all FSP papers and briefs are also submitted to the USAID Development Experience Clearing House (DEC) at: http://dec.usaid.gov/

AUTHORS

Christine Sauer is Graduate Research Assistant, Department of Agricultural, Food, and Resource Economics, Michigan State University.

Nicole Mason is Assistant Professor, Department of Agricultural, Food, and Resource Economics, Michigan State University.

Mywish Maredia is Professor, International Development, Department of Agricultural, Food, and Resource Economics, Michigan State University.

Rhoda Mofya-Mukaka is a Research Fellow with the Indaba Agricultural Policy Research Institute, Zambia

This study is made possible by the generous support of the American people through the United States Agency for International Development (USAID) under the Feed the Future initiative. The contents are the responsibility of the study authors and do not necessarily reflect the views of USAID or the United States Government

Published by the Department of Agricultural, Food, and Resource Economics, Michigan State University, Justin S. Morrill Hall of Agriculture, 446 West Circle Dr., Room 202, East Lansing, Michigan 48824, USA

ACKNOWLEDGMENTS

This study was supported by the USAID-funded Feed the Future Innovation Lab for Collaborative Research on Grain Legumes under the terms of Cooperative Agreement No. EDH-A-00-07-00005-00, the USAID-funded Food Security Policy Innovation Lab under the contract number AID-OAA-L-13-00001 (Zambian buy-in), and USAID Mission to Zambia through grant number 611-A-00-11-00001-00. The opinions expressed in this paper are those of authors alone and should not be attributed to USAID, the Legume Innovation Lab or the Food Security Policy Innovation Lab.

ABSTRACT

Despite the many potential benefits of legume cultivation, there is scarce empirical evidence on whether and how producing legumes affects smallholder farm households' food security. We use nationally representative household panel survey data from Zambia to estimate the differential effects on cereal-growing households of incorporating legumes into their farms via cereal-legume intercropping, cereal-legume rotation, and other means. Results suggest that cereal-legume *rotation* is positively and significantly associated with households' months of adequate food provisions, and calorie and protein production. In contrast, cereal-legume *intercropping* generally has no statistically significant effect on the indicators of food security of Zambian smallholders.

Key words: legumes, crop rotation, intercropping, food security, nutrition, smallholder farm households, Zambia, Africa

JEL codes: Q12, Q15, Q16, I31

Table of Contents

ABSTRACT v

1. Introduction 1

2. Conceptualizing the Role of Legumes in the Causal Pathways from Agriculture to Food and Nutrition Security 3

3. Data 5

3.1. Data source and attrition 5

3.2. Outcome variables 6

4. Empirical Strategy 7

4.1. Estimation strategy 7

4.2. Control variables 10

5. Results 11

5.1. Descriptive Analysis: Importance of cereals and legumes in the Zambian smallholder cropping systems 11

5.2. Effects of Cereal-legume Intercropping 12

5.3. Effects of Cereal-Legume Rotation 13

5.5 Effects of Other Legume Practices 13

5.6. Effects of Agricultural Income and Calorie Production on HDDS and MAHFP 14

6. Conclusion 14

REFERENCES 16

1. Introduction

In recognition of the myriad benefits of legume production, the Food and Agriculture Organization (FAO) of the United Nations has declared 2016 as the International Year of Pulses.[1] Legume production and consumption have the potential to impart several environmental, economic, and nutritional benefits. As natural nitrogen fixers, legumes reduce the need for inorganic fertilizer and can improve the environmental sustainability of cropping systems, and the residual nitrogen in the soil can enhance long-term soil fertility and crop productivity (Bohlool et al. 1992, Dakora and Keya 1997, Thierfelder et al. 2012). Legumes also help control cereal crop diseases and pests, which in turn reduces the need for costly pesticides (Bohlool et. al. 1992, Howieson et al. 2000). Along with the potential positive environmental effects of legume cultivation, legumes carry many potential economic and nutritional benefits for smallholder farm households. For example, these crops can be stored for long periods of time with no loss of nutritional value, which grants farmers the choice to consume or sell the legumes between harvests (FAO 2016). Additionally, parts of the legume plant (e.g., the leaves of cowpea and bean plants) can be eaten during the growing season, offering some insurance against food insecurity (Barrett 1990). Due to their high protein, mineral, and fiber content, legumes are a valuable supplement to a carbohydrate-based diet (Tharanathan and Mahadevamma 2003, Ojiewo et. al. 2015).

Given the multi-faceted role that legumes can potentially play in the production and dietary systems of many developing countries, legumes are receiving increasing attention in the agricultural development funding strategies of international research organizations and donor agencies, such as the CGIAR, the U.S. Agency for International Development, the Bill and Melinda Gates Foundation, and others (Murrell 2016). In response to the persistence of malnutrition as a global public health concern, legumes feature prominently as a strategic food group in the pathways linking agriculture to better nutritional outcomes. These agriculture-nutrition linkage pathways are conceptualized to include increased production of more and nutritious foods for self-consumption; increased agricultural income through increased production or productivity that can be used to purchase nutritious food and better health care; increased use of technologies and systems that improve or preserve the nutritional content of foods throughout the food supply chain (from the farm level, to storage, processing, marketing, and final consumption); and increased empowerment of women to enhance their control over resources, knowledge and status (World Bank 2007, Hawkes et al. 2012, Chung 2012, Gillespie et al. 2012, Ruel et al. 2013, Herforth and Harris 2014; see also Figure 1).

Despite the many potential benefits that legumes might have for smallholders, the relationship between legume cultivation and household food security has not been rigorously analyzed in the literature. This study is designed to build an evidence base by exploring pathways through which

---

[1] Pulses are a subgroup of legumes that are harvested for dry grain. Examples include navy beans, kidney beans, chickpeas, and cowpeas.

legumes can potentially enhance agriculture-food security linkages. Specifically, we examine the links between the various ways in which households incorporate legumes into their cropping activities (namely, cereal-legume rotations, cereal-legume intercropping, and other means such as legume monocropping or intercropping legumes with non-cereal crops)[2] and several indicators of household food security and welfare along the agricultural production and income pathways.

To the best of our knowledge, no previous study has explicitly analyzed the causal links between these legume technologies and household food security. This paper attempts to fill that gap by using nationally-representative panel survey data from smallholder households in Zambia. Specifically, we use instrumental variables and panel data techniques including fixed effects and correlated random effects approaches to measure the impacts of these legume technologies on net crop income, per capita calorie and protein production, months of adequate household food provisions (MAHFP), and household dietary diversity score (HDDS). These indicators influence household food security, which is considered a necessary (but not sufficient) condition for achieving nutrition security (see, for example, FAO 2009).[3] We thus explore the role of legume technologies in this broader agriculture-nutrition-food security nexus, but with a focus on food security.

As a preview of our results, we find that cereal-legume rotation has positive and statistically significant effects on Zambian smallholders' MAHFP and per capita calorie and protein production. These results are robust to the estimator used. We find little evidence of statistically significant cereal-legume intercropping effects on the outcome variables studied here, and some evidence of positive effects for other forms of legume production, but the latter are quite sensitive to the estimator used.

The remainder of the paper is organized as follows. Section 2 draws from the literature and describes the conceptual framework underlying the empirical analysis of the paper. In Sections 3 and 4 we describe the data and detail our empirical strategy. We present the results in Section 5 and conclude in Section 6.

---

[2] Throughout the remainder of the paper, we use the term "legume technologies" to refer collectively to these three means by which households incorporate legumes into their farms (cereal-legume rotations, cereal-legume intercropping, and other means). The legumes commonly grown in Zambia and included in this study are groundnuts, soybeans, mixed beans, cowpeas, velvet beans, and bambara nuts. The cereals considered for cereal-legume rotation and intercropping are maize, sorghum, and millet. Rice is also grown by Zambian smallholders but it is not very conducive to intercropping or rotating with legumes because the aforementioned legumes generally do not grow well in flooded paddy fields.

[3] *Food security* exists when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2002). The four commonly recognized dimensions of food security are food availability, access, utilization, and stability. *Food and nutrition security* exists when "all people at all times have physical, social and economic access to food, which is consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life" (Wüstefeld 2013). Three key dimensions of nutrition security are "access to adequate food, care and food practices, and sanitation and health" (ibid).

2. Conceptualizing the Role of Legumes in the Causal Pathways from Agriculture to Food and Nutrition Security

There are different approaches used in the literature to conceptualize causal pathways from agriculture to nutrition and health (see Webb 2013 for a review). Most of these approaches are based on theorized causal pathways that build on the understanding that agriculture can influence nutrition and health through multiple pathways (direct and indirect), and that food alone is not enough. For example, Headey et al. (2011) and Gillespie et al. (2012) talk of seven pathways, which include agriculture as the direct and indirect (via income) source of food at household level. Other pathways include macro-level agricultural policy as a driver of prices and agriculture as an entry-point for enhancing women's control over resources, knowledge and status. The frameworks by Hawkes et al. (2012) and Chung (2012) elaborate on elements not frequently highlighted, such as micronutrient deficiency versus anthropometry, nutrient quality/bioavailability, food value chains, and demand creation for health services through knowledge and nutrition education.

The framework developed in a more recent study by Herforth and Harris (2014) highlights three main pathways linking agriculture to nutrition: food production, agricultural income, and women's empowerment (Figure 1). **Food production** impacts a household's nutritional status through the type, quantity, and seasonality of food available for consumption (Chung 2012, Herforth and Harris 2014). That is, the broader food market environment influences a household's decision of what to produce and consume. If a preferred food is not available or affordable in the local market, a household may instead choose to grow that crop on their farm (Herforth and Harris 2014). As a second pathway, an increase in **agricultural income** could result in increases in food expenditure, which could result in higher levels of dietary diversity and more food consumption overall. More agricultural income might also translate into higher non-food expenditure, including expenditure on health care, which could directly raise a household's nutritional status. **Women's empowerment**, as a third pathway in this framework, emphasizes women's combined roles in agriculture, dietary choices and healthcare, and how they influence the nutritional outcomes for both child and mother (Figure 1). Note that these are some of the same pathways that link agriculture to household food security, which is different from but closely linked to nutrition security.

For a nutrition-focused agricultural strategy, legumes serve as a perfect conduit to unravel the linkages between agriculture and nutrition across all three of these pathways. A production system that includes a greater variety of foods grants the household a greater diversity of food for own consumption. For example, the study by Jones et al. (2014) indicates that a more diverse production system (measured with a simple crop count, a crop and livestock count, and with a Simpson's index) was positively and significantly correlated with dietary diversity indices, and with the number and frequency of legumes, fruits, and vegetables consumed. Thus, under the food production pathway, we expect that households that integrate legumes into their cropping activities, be it by intercropping with cereals, rotating with cereals, or by other means, would have more and diverse availability of food.

Moreover, much of the research suggests a positive relationship between legume intercropping/rotation and crop yields. Legumes have a unique role in sustaining soil fertility through symbiotic biological nitrogen fixation, which serves as a mechanism for boosting crop yields in the system. There is extensive experimental evidence showing that the integration of grain legumes in the farming system significantly increases the yields of the subsequent crop in the rotation (Jeranyama *et al.*, 2007; Kamanga *et al.*, 2010; Lunze *et al.*, 2011; Odhiambo *et al.*, 2011; Chauhan *et al.*, 2012; Lunze & Ngongo, 2012; Thierfelder *et al.*, 2012). There are also impact studies based on observational data that support this linkage between legume intercropping or rotation and cereal productivity. For example, using plot-level data from a household panel survey of Zambian smallholders to model the impact of potentially climate-smart agriculture practices (e.g., minimum soil disturbance, crop rotation, and legume intercropping), Arslan et al. (2015) show that legume intercropping had a positive and significant effect on maize yield. However, the effect of crop rotation on maize yield by this same study was shown to be negative. Kassie et al. (2015) used an endogenous switching regression approach to examine the effects of maize-legume intercropping and rotation and minimum tillage on maize productivity in Malawi. Their results indicate that these practices had a positive and significant impact on maize yield. Similarly, Manda et al. (2016) find a positive effect of maize-legume rotation, improved maize varieties, and residue retention on maize yield in rural Zambia.

Higher crop productivity caused by the presence of legumes in the cropping system as shown by the experimental and observational studies above makes more food available for sale and consumption, thus potentially influencing both production and income pathways. Additionally, since legume crops are often produced and managed by women, they also provide income and direct access to nutritious foods that can increase dietary choices available for women themselves and for their children. Thus, legumes also play an important role in the third pathway: women's empowerment.

In this paper, we explore the role of legume-based practices (cereal-legume intercropping, cereal-legume rotation, and other means by which households incorporate legumes into the cropping activities) in influencing some intermediate indicators along these pathways linking agriculture to food security and nutrition outcomes. Figure 2 summarizes the conceptualized pathways of how the adoption of these legume technologies could affect household food security and nutritional status. The green boxes highlight the role legumes play along the three pathways discussed above: food production, crop income, and women's empowerment. Within the framework shown in Figure 2, we explore the effect of adoption of the various legume technologies on indicators along the three nodes depicted by the solid red line: food production, crop income, and adequate and diverse food intake—two indicators of food security. Specifically, we test the hypotheses that cereal-growing smallholder farm households that integrate legumes into their production system would have: 1) more availability of food as measured by total production of calories and protein (food production pathway); 2) more income from crop production (crop income pathway); and 3) more months with adequate food access and more diverse diets (a combination of production, income and women empowerment pathways). Due to lack of data we are not able to examine other nodes along this production-income-food security-nutrition pathway nor able to explore the role of legume technologies in contributing to the health status and nutrition outcomes.

3. Data

3.1. Data source and attrition

The data for this study are from the Rural Agricultural Livelihoods Survey (RALS), a two-wave, nationally representative panel survey of Zambian smallholder farm households conducted in June-July 2012 and 2015 by the Indaba Agricultural Policy Research Institute.[4] The 2012 survey covered the 2010/11 agricultural year (October 2010-September 2011) and the associated crop marketing year (May 2011-April 2012). The 2015 survey covered the 2013/14 agricultural year and the 2014/15 crop marketing year. The RALS data include detailed information on household demographics, crop production (e.g., input use, area planted, and quantities harvested by plot and crop, as well as plot-level information on the use of intercropping and the main crop that was planted on the plot in the previous agricultural year), crop sales, asset holdings, and access and distances to agricultural extension, *inter alia*. From these data, we compute net crop income, defined here as the gross value of crop production minus fertilizer costs. (Insufficient data are available to net out other input costs; however, fertilizer is the major cash input cost incurred by Zambian smallholder farmers.) Both RALS survey waves also capture households' months of adequate household food provisions (MAHFP; Bilinsky and Swindale, 2010), and the 2015 wave included a household dietary diversity score (HDDS) module (Swindale and Bilinsky 2006). These data allow us to analyze the effects of legume technologies on five household-level welfare indicators: net crop income, calories produced/capita/day, protein produced/capita/day (in grams), MAHFP and HDDS.[5] The rationale for and more details on these outcome variables are provided in the next sub-section.

A total of 8,839 households were interviewed in the 2012 RALS. Of these, 7,254 (82.1%) were successfully re-interviewed in 2015. Given this non-trivial rate of attrition, we tested for attrition bias using the regression-based test recommended by Wooldridge (2010, p. 837). Based on these tests, we fail to reject the null hypothesis of no attrition bias for the crop income, protein produced/capita/day, and MAHFP outcome variables ($p>0.10$); only for calories produced/capita/day do we reject the null of no attrition bias at the 10% level or lower, but only marginally so ($p=0.098$). The weight of the evidence therefore suggests attrition bias is not a major concern in this study.[6] Because we are interested in how incorporating legumes into their cropping

---

[4] In Zambia, smallholder households are defined as those cultivating less than 20 ha of land. For details on the RALS sample design, see IAPRI (2012, 2015).

[5] Total calories produced/capita/day and total protein produced/capita/day are calculated by multiplying the kg produced of each crop by the estimated calories/kg and protein/kg, respectively, then dividing by the number of household members and 365 days. Calorie and protein conversion factors are from FAO (1968).

[6] We cannot test for attrition bias for HDDS because it was only collected in the 2015 RALS.

activities affects cereal- (i.e., maize-, sorghum-, or millet-) growing households, our analytical sample consists of all panel households that grew a cereal crop in both the 2010/2011 and 2013/2014 agricultural seasons (N=6,226).

3.2. Outcome variables

The five outcome variables analyzed correspond to different nodes along the agriculture-food security-nutrition pathway illustrated in Figure 2. MAHFP and HDDS are both household-level indicators related to food access, an important dimension of food security (Swindale and Bilinsky 2006, Bilinsky and Swindale 2010); the other dimensions of food security are availability, utilization, and stability. Household food access is defined as "the ability to acquire sufficient quality and quantity of food to meet all household members' nutritional requirements for productive lives" (Swindale and Bilinsky 2006, p. 1). While HDDS measures dietary diversity, an indicator of access to food *quality*, MAHFP measures the duration of an adequate *quantity* of food accessed by the household. Note that HDDS is not a direct indicator of nutritional status; but it is positively correlated with nutrition indicators such as child anthropometric status (ibid.). By also analyzing household crop income and household production of calories and protein, we can unpack the pathways through which legumes affect household food security and potentially nutritional outcomes (which are not examined in this paper). (Recall the agricultural/crop income and food production pathways in the conceptual frameworks depicted in Figures 1 and 2.) In the remainder of this section, we describe the MAHFP and HDDS in more detail.

The MAHFP module in the 2012 and 2015 RALS asks households in which months, if any, it did not have enough food to meet its needs during the most recent crop marketing year (May-April). The resultant MAHFP outcome variable is an integer ranging from 0-12, with a higher value indicating more months with adequate household food provisions and thus greater household food security (Bilinsky and Swindale 2010). Leah et al. (2012) note that MAHFP is a particularly good indicator to use with agricultural populations because it captures a household's ability to meet its food needs over the course of a year.

The HDDS variable is constructed using data from a dietary diversity module included in the 2015 RALS. Interviewees were asked if anyone in the household consumed anything out of 16 different food groups (such as cereals, dark green leafy vegetables, and flesh meat) in the past 24 hours. Some of these categories were then combined for a total of 12 food categories as in the standard HDDS tool (Swindale and Bilinsky 2006). The HDDS outcome variable is then an integer ranging from 0-12 that reflects a count of how many food groups were consumed by the household in the past day, with a higher number indicating greater dietary diversity. Hoddinott and Yohannes (2002) find that dietary diversity is positively associated with per capita consumption and per capita caloric availability from both staple foods and non-staples, suggesting that HDDS is a useful (and easy to implement) indicator of overall household food security. Although the HDDS provides a good measure of the breadth of food groups consumed by the household, it does not measure quantity consumed or the intra-household distribution, and it does not indicate a household's habitual dietary pattern (Kennedy et al. 2013).

Before turning to the empirical strategy, it is important to highlight the timing of farmers' use of the legume technologies that is captured in the RALS data vis-a-vis the reference periods for the various outcome variables described above. Use of the legume technologies is captured for the agricultural year (October-September), with crop choice, planting, intercropping, and crop rotation decisions typically made between October and January (Figure 3). The main harvest period is May-June, and the crop income and calories and protein produced outcome variables capture the quantities harvested of all crops planted (and affected by agricultural technologies and management practices employed) during that agricultural year. We therefore capture the *contemporaneous* effects of the legume technologies on crop income, and calories and protein produced. There may also be lagged effects of these technologies on these outcome variables but the RALS data do not enable us to capture these effects. The MAHFP variable reflects the status of household food provisions from the beginning of the main harvest period (May) through the following April (Figure 3). Finally, the reference period for the HDDS variable is the 24 hours prior to the time of interview, approximately one year after the main harvest that reflects the contemporaneous effects of the legume technologies (Figure 3). Given this timing, if we were to find effects of the legume technologies on HDDS in this study, they would reflect more lagged, enduring impacts.

4. Empirical Strategy

4.1. Estimation strategy

4.1.1. Estimating the impact of legume technologies on household welfare

Despite the many potential benefits of cereal-legume rotations, intercropping, and other legume technologies, it is notoriously difficult to rigorously assess the impacts of technology adoption. Adoption of legume technologies is likely endogenous to household incomes and food security (which we subsequently refer to as 'household welfare' or 'welfare indicators' for sake of brevity). A household that adopts a new technology usually does so voluntarily and the decision of whether or not to adopt is likely correlated with unobserved factors affecting household welfare. This complicates the estimation of the causal effects of these technologies along the impact pathways depicted in Figure 2. An oft-cited example is that more motivated households or those with better management ability are more likely to adopt improved technologies. If this were the case and motivation or management ability were unobservable and also positively correlated with household crop income, for example, then ordinary least squares (OLS) estimates of the effects of the adoption of a given technology on household crop income would be biased upward.

Randomly assigning technology *adoption* is also difficult, if not impossible, to achieve, although it may be possible to, for example, randomly assign exposure to or additional training on a given technology. However, in this study, we rely on observational data on the adoption of legume technologies and household welfare, and so must employ quasi-experimental techniques to identify the welfare effects of cereal-legume intercropping and rotation and other legume combinations. More specifically, we use panel data methods (e.g., the fixed effects estimator and the correlated random effects approach) or two-stage least squares to control/correct for different sources of endogeneity. For the purpose of comparison, we also report OLS estimates for all outcome variables.

For all outcome variables except for HDDS, which is only observed in the 2015 RALS, we estimate household fixed effects (FE) models of the welfare indicators regressed on measures of the household's adoption of the various legume technologies (cereal-legume intercropping, cereal-legume rotation, and other legume technologies), and a vector of control variables that are described in the next sub-section and are listed in Table 1.[7] Adoption of the various legume technologies is measured as either: (i) a binary 'treatment' variable equal to one if the household practiced the legume technology on at least one plot, and equal to zero otherwise; or (ii) a continuous 'treatment' variable equal to the household's total hectares under the legume technology.[8] Under the key assumption of strict exogeneity of the observed covariates conditional on the unobserved time-constant household-level heterogeneity, the FE estimates of the welfare effects of legume technology adoption will be unbiased and consistent. If, for example, a household's motivation and management ability did not vary between the 2012 and 2015 waves of the RALS, then the FE approach may largely solve the endogeneity problem.

Given the count-variable nature of the MAHFP, we also attempted to estimate correlated random effects negative binomial (CRE-NB) models for this outcome variable. (Unfortunately, these CRE-NB models did not converge for MAHFP but because we also estimate similar models for HDDS, we retain the discussion of this estimation approach here.) The NB portion directly models the count dependent variable; it is also more flexible than a Poisson model in that it does not assume an equal mean and variance – a property that was rejected in our data. Combining NB with the CRE approach (Mundlak 1978; Chamberlain 1984) allows us to take advantage of the panel nature of the RALS data on MAHFP and control for time-constant unobserved household-level heterogeneity. Note that with nonlinear-in-parameters models like NB, using a fixed effects approach instead of CRE would result in biased estimates due to the so-called incidental parameters problem (Wooldridge 2010). Two key assumptions for the CRE estimates to be unbiased and consistent are strict exogeneity and that the time-constant unobserved household-level heterogeneity be a linear function of the household time averages of the observed covariates, such that including these time averages as additional covariates in the regression effectively controls for the unobserved heterogeneity (ibid.).

---

[7] We tested for differential effects on household welfare of cereal-legume rotation depending on whether the plot was in cereals or in legumes in the current agricultural year. These results suggest no differential effects by phase of the cereal-legume rotation.

[8] For cereal-legume intercropping, this is measured as the hectares planted to legumes on cereal-legume intercropped fields.

We take a related, though slightly different, approach with the HDDS outcome variable. Because this variable is observed only in the 2015 RALS, we cannot estimate household FE models; however, because we observe all *explanatory* variables in both waves of the RALS, we can take a CRE-like approach to somewhat control for time invariant unobserved heterogeneity (ibid.). More specifically, we estimate linear CRE and CRE-NB models in which the RALS 2015 HDDS is regressed on the RALS 2015 levels of the covariates as well as the RALS 2012 and 2015 household time averages of the covariates.

Finally, for all outcome variables, we estimate two-stage least squares (2SLS) regressions in which we instrument for the three main explanatory variables of interest, which we suspect may be endogenous to household welfare: adoption of cereal-legume intercropping, of cereal-legume rotation, and of other legume technologies.[9] To do this, we need at least three instrumental variables (IVs), and these must be strongly partially correlated with the suspected endogenous variables but uncorrelated with the idiosyncratic error term in the welfare indicators equations (i.e., uncorrelated with the dependent variable *except* through the endogenous variable). We use as IVs the following three variables: (i) a dummy variable equal to one if any member of the household received advice on rotating cereals with legumes/nitrogen-fixing crops during or prior to the agricultural year in question (i.e., 2010/11 and 2013/14 for RALS 2012 and 2015, respectively), and equal to zero otherwise; (ii) a similar dummy variable for if any member of the household received advice on intercropping cereals with legumes/nitrogen-fixing crops; and (iii) a variable that captures the prevalence of legume cultivation in the household's community, and is defined as the percentage of other households in the standard enumeration area that grew legumes (excluding the household itself).[10] We next discuss the strength of these IVs and our arguments for the exclusion restrictions.

First stage regression results of the suspected endogenous explanatory variables on the three IVs and the exogenous covariates suggest that the cereal-legume intercropping and rotation advice dummies and the legume prevalence variable are quite strongly partially correlated with the use of these practices (see Tables A1 and A2 in the Appendix). As expected, receipt of advice on intercropping (rotating) cereals with legumes/nitrogen-fixing crops is positively and statistically significantly associated with households adopting cereal-legume intercropping (rotation). Also as expected, an increase in the prevalence of legume production among other households in a community is positively and significantly associated with a given household's adoption of other legume technologies. The partial F statistics for the excluded IVs exceed 10 in all six models in which we use the 2012 and 2015 RALS panel data. This suggests that the IVs are quite strong when both waves of the data are used. However, when we use only the 2015 RALS cross-section, the partial F statistics exceed 10 in three out of the six models but fall below 10 for the remaining two models.

---

[9] These 2SLS models are estimated using the 2015 RALS data for HDDS, and the pooled 2012 and 2015 RALS data for the other outcome variables. We explored estimating fixed effects instrumental variables (FE-IV) models for the latter but were unable to identify sufficiently strong instruments.

[10] The standard enumeration area is the most disaggregated geographic unit in the dataset and is typically a cluster of two to four villages that contains a total of 150 to 200 households.

Note that these weaker IVs affect the HDDS 2SLS regressions, which we can only run with the 2015 cross-section. Overall, based on the Staiger and Stock (1997) rule of thumb of partial F>10, the first stage results suggest that the candidate IVs are sufficiently strong to be used in the 2SLS regressions with the 2012 and 2015 RALS panel data but weak IVs are a concern for the HDDS 2SLS regressions; thus, the latter results must be interpreted with caution.

Regarding the exclusion restrictions, because we control for distance to the nearest agricultural extension office in both the first and second stage regressions, the advice IVs should be uncorrelated with the idiosyncratic error term in the welfare indicators equation. That is, conditional on a household's access to extension advice, receipt of specific advice about legume intercropping and rotation should be exogenous to household welfare. For the third IV, we argue that conditional on the extensive set of control variables included in the model (see the next sub-section), we expect the prevalence of legume cultivation among *other* households in household *i*'s community to only affect the welfare of household *i* through its effect on household *i*'s own cultivation of legumes. Moreover, the decisions of other households to grow legumes should be exogenous to household *i*.

4.1.2. Estimating the impact of crop income and production on food security

In addition to estimating the direct effects of cereal-legume intercropping, rotation, and other legume practices on household welfare, we explore the impact of net crop income and per capita daily calorie production on HDDS and MAHFP. In doing so, we test the hypotheses that increased agricultural income and higher levels of crop productivity are the pathways through which legume technology affects household food security (recall Figure 2).

The estimators we use to analyze this link in the agriculture-nutrition chain are (P)OLS (for both HDDS and MAHFP models) and CRE-NB for the HDDS models. CRE-NB did not converge using MAHFP as the dependent variable. We also estimate a fixed effects model with MAHFP. We explored using 2SLS but were unable to identify sufficiently strong IVs, and we failed to reject the null hypothesis of no exogeneity of the key explanatory variables of interest (net crop income and calorie production).

4.2. Control variables

The control variables included in our main empirical models are motivated by a non-separable agricultural household model. In such models, consumption and production decisions are made jointly, and so we include consumer demand determinants and producer supply determinants in the regressions for both the consumption-related outcome variables (i.e., HDDS and MAHFP) and the production-related outcome variables (i.e., net crop income and calorie and protein production). The consumer demand determinants included in the models are household demographic variables such as the age, gender, and education level of the household head and the number of members in the household, as well as the provincial median retail price of maize meal (i.e., maize flour, an important food staple) during the hungry season. The producer supply determinants included in the models are the household's agricultural assets (total landholding size and per capita landholding size, number of fields operated, average plot size, livestock owned, and farm equipment owned) and proxies for access to agricultural information and markets (i.e., whether the household owns a radio or cell phone and the distance to the nearest agricultural extension office, market town, and paved road). We also include district-level basal and top dressing fertilizer prices. Finally, we include a year dummy equal to one for the 2015 RALS to control for unobserved changes between the two survey rounds that affect all households, and a dummy equal to one if the household is rural. District and year interaction terms are also included in the panel models to control for location and time specific unobservables and variables for which we do not currently have data (e.g., rainfall, soil quality, and lagged producer prices).[11] See Table 1 for more detailed variable descriptions and summary statistics based on the RALS 2015 data.

The regressions of HDDS and MAHFP on crop income and calorie production contain many of the same explanatory variables as the main models. These include the vector of household demographics, the proxies for access to information and markets, the price of commercial maize meal, and district and year interaction terms. The full list of controls, excluding the district and year dummies, is given in Table 6.

5. Results

Figure 4 and Table 2 provide information on the adoption of the various legume technologies by cereal-growing smallholder households in Zambia during the 2010/11 and 2013/14 agricultural seasons. Tables 3, 4, and 5 summarize the key findings from the regression analysis – i.e., the estimated effects of cereal-legume intercropping, cereal-legume rotation, and other legume practices, respectively, on the five key outcome variables discussed above. The full regression results for the FE models are reported in Table A3 in the Appendix. (The other full regression results are available from the authors upon request.) We begin with a brief descriptive analysis and then discuss the effects of each legume technology in turn. Lastly, we discuss the effects of net crop income and calorie production on HDDS and MAHFP to understand which pathway is contributing to these effects, if present.

5.1. Descriptive Analysis: Importance of cereals and legumes in the Zambian smallholder cropping systems

Legume cultivation is fairly common among cereal-growing smallholder households in Zambia. Approximately 60-64% of such households grow legumes in some way (Figure 4). The most common way that Zambian smallholders incorporate legumes into their farms is via rotation with cereals – approximately 40-43% of households do this each year. In contrast, cereal-legume

---

[11] The district-year interaction terms are included in all regressions except for the 2SLS models, in which we suspect they erased much of the variation in, and consequently weakened, our IVs.

intercropping is practiced by less than 5% of households each year (Figure 4). Approximately 22-23% of households grow legumes via other means (e.g., legume monocropping or rotation/intercropping with other crops). Among legume crops, groundnuts are the most popular (53% of cereal-growing households grew groundnuts in the 2013/14 agricultural year), followed by mixed beans (about 17% of households), soybeans (8% of households), and Bambara nuts and cowpeas (3% of households each); just 0.1% of households grew velvet beans.

The results in Table 2 suggest that there is considerable within-household variation over time in the use of legume technologies – e.g., not all households that use a given technology in one survey wave use it in the other survey wave. This is important given that the use of the (household) FE estimator is a key part of our identification strategy.

5.2. Effects of Cereal-legume Intercropping

Turning to the econometric results in Table 3, cereal-legume intercropping exhibits few statistically significant ($p<0.10$) effects on the outcome variables examined in this study, particularly when we use 2SLS or panel data methods to address endogeneity concerns. Only for HDDS do we find statistically significant effects that are retained across multiple non-OLS estimators. The results suggest positive and statistically significant cereal-legume intercropping effects on HDDS in three of eight models. Moreover, the 2SLS estimates of the effects of intercropping on HDDS are unreasonably large in magnitude (at 9.4 for the binary treatment variable and 13 for the continuous treatment variable); this is likely due to the IVs being relatively weak for intercropping when only the 2015 RALS data are used (as is the case for the HDDS regressions).

In general, the results in Table 3 suggest that cereal-legume intercropping has little or no statistically significant effects on HDDS and MAHFP, two indicators of the food access dimension of food security,[12] at least at the time lags captured in this study. Recall that the MAHFP variable used here reflects household food access during the 12 months following the main harvest of a cereal-legume intercropped field, and that the HDDS variable used here is measured approximately one year after that harvest. Particularly for HDDS, this may be too long of a lag after harvest for there to be measurable effects on HDDS. There may be shorter-term effects of cereal-legume intercropping on HDDS but we are not able to capture them with the data used here. Consistent with the lack of statistically significant effects on MAHFP, we also find little evidence of statistically significant cereal-legume intercropping effects on households' crop income and food production (calories and protein produced), which are two of the three main intermediate outcomes through which legume technologies are hypothesized to affect food security and nutrition (recall Figure 2). Overall, the evidence suggests that compared to households that do not practice cereal-legume intercropping, cereal-growing households who intercrop cereals with legumes reap little incremental benefits on the welfare indicators used here.

---

[12] Also recall that increases in HDDS are positively associated with increases in child nutrition outcomes (Swindale and Bilinsky 2006).

5.3. Effects of Cereal-Legume Rotation

In contrast to cereal-legume intercropping, cereal-legume rotation has more statistically significant, and generally positive, effects on household welfare (Table 4). The results are not robust to the choice of estimator for HDDS (although they are positive where statistically significant), but for MAHFP, calorie production, and protein production, the majority of the estimates suggest that cereal-legume rotation positively affects these outcome variables. The FE results, for example, suggest that MAHFP increases by an average of 0.05 units with the use of cereal-legume rotation, and by an average of an additional 0.05 units given a one-hectare increase in cereal-legume rotations, ceteris paribus.

The positive effects of cereal-legume rotation on MAHFP appear to be coming mainly through the food production pathway, as cereal-legume rotation significantly increases both household calorie and protein production but has mixed effects on household crop income (Table 4). The statistical significance of the calorie and protein production results is quite robust across estimators, but the 2SLS estimates are much larger in magnitude than the POLS and FE estimates. In terms of the magnitudes of the effects, the FE results, for example, suggest that each additional hectare of cereal-legume rotated land increases calorie production by an average of 1,088 calories/capita/day and protein production by an average of 38 grams/capita/day, holding other factors constant. These are substantial increases vis-à-vis the sample means of 5,913 calories/capita/day and 158 grams of protein/capita/day.

In summary, cereal-legume rotation appears to have generally positive effects on household food access (especially MAHFP) and on per capita calorie and protein production. The impact of rotation on net crop income is not as clear.

5.5 Effects of Other Legume Practices

The results for the effects of other legume technologies on household welfare are quite sensitive to the estimator being used. For example, the CRE and CRE-NB results suggest that, holding other factors constant, households that adopt a legume technology like legume monocropping have on average an HDDS that is between 0.17 and 0.26 points higher than the HDDS of households that do not adopt such a practice. However, after correcting for endogeneity via 2SLS, the results suggest that other legume technologies *negatively* affect HDDS. None of the results are statistically significant in the MAHFP models (Table 5).

For net crop income, the results are very sensitive to the estimator used and to the specification of the ‘treatment’ variable (binary vs. continuous), and many are not statistically different from zero. There is some evidence of positive effects on calorie and protein production using the OLS and FE estimators. For example, the FE results indicate that each additional hectare of land planted with other legume combinations increases calorie (protein) production by an average of 1,130 calories (55 grams)/capita/day, ceteris paribus. The statistical significance disappears, however, when the 2SLS estimator is used.

To summarize, while we find some evidence of positive effects of other legume technologies on each of the welfare indicators examined here, the results are quite sensitive to the model specification and estimator used.

5.6. Effects of Agricultural Income and Calorie Production on HDDS and MAHFP

To test the pathway through which the legume technologies studied here affect household dietary diversity and months of adequate food provisions, we also ran separate regressions of HDDS and MAHFP on net crop income and calorie production. The coefficients are generally positive and significant, although quite small in magnitude (Table 6). For example, the OLS results indicate that an increase in daily net crop income of one ZMW leads to an average 0.004 point increase in HDDS and a 0.01 point increase in MAHFP, ceteris paribus. In other words, an increase in net crop income of 10 ZMW per day (which is roughly equivalent to an increase of $1/day) increases HDDS by 0.04 points and MAHFP by 0.1 points, holding all else equal. This result for MAHFP is very similar to the coefficients on the cereal-legume rotation variables in the main regressions (Table 4), where we found, for example, that a one-hectare increase in area that is cereal-legume rotated increases MAHFP by an average of 0.09 points, ceteris paribus. After controlling for time-constant unobserved heterogeneity with the FE estimator, we still find statistically significant benefits of increased income on MAHFP: an increase of 10 ZMW in per diem agricultural income leads to a 0.05 point increase in MAHFP, ceteris paribus. It therefore seems plausible that some of the positive benefit of rotation on MAHFP is due in part to the income pathway.

Turning to the effects of calorie production on HDDS and MAHFP, the OLS estimates suggest that one additional calorie produced per capita and per day is associated with a 0.00002 point increase in HDDS and a 0.000008 increase in MAHFP, holding other factors constant. That is, if a household increases its calorie production/person/day by 2,000 calories, the average resulting increase in HDDS (MAHFP) is 0.04 (0.016) points. Compared to the sample averages of 5.71 and 10.42, this is an increase of less than 1%. These results thus suggest that, although the practical effects may be limited, cereal-legume intercropping, rotation, and other legume practices positively and statistically significantly affect HDDS and MAHFP through both the income and crop production pathways.

6. Conclusion

Overall, the results suggest that intercropping cereals and legumes has little or no statistically significant effect on household welfare as measured by the indicators used here. This may partially explain the low adoption of this practice by farmers in Zambia. In contrast, cereal-legume rotation is strongly positively associated with most of the outcome variables considered. Households that rotate reap the benefits of having a greater range of food groups and more calories and protein to eat, and have sufficient food in more months of the year than households that do not practice cereal-legume rotation. Additionally, we find some evidence of positive effects of other legume technologies on household welfare, but the results are not as robust as those for cereal-legume rotation. These effects appear to come through both the crop income pathway and the agricultural production pathway.

From a policy perspective, given the empirical evidence that cereal-legume rotations can improve household food production and food access among Zambian smallholder cereal growers, the Zambian government through its extension service as well as NGOs and private sector actors working in the agricultural sector should share the information about the benefits of this technology more widely so that farmers may take up this practice where it is feasible and beneficial for them to do so. Moreover, researchers at the Zambian Agriculture Research Institute together with social scientists should investigate the specific types and lengths of cereal-legume rotations that are the most welfare-enhancing for Zambian smallholders. Further research is also needed to understand the low adoption rates of cereal-legume intercropping among Zambian smallholders, and to identify and promote specific cereal-legume intercrops that meet farmers' needs.

REFERENCES

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., Cattaneo, A., & Kokwe, M. (2015). Climate smart agriculture? Assessing the adaptation impacts in Zambia. *Journal of Agricultural Economics,* 66(3), 753-780.

Barrett, R.P. (1990). Legume species as leaf vegetables. In J. Janick & J.E. Simon (Eds.), *Advances in New Crops* (pp. 391-396). Retrieved May 23, 2016 from https://hort.purdue.edu/newcrop/proceedings1990/V1-391.html

Bilinsky, P. & Swindale, A. (2010). Months of Adequate Household Food Provisioning (MAHFP) for Measurement of Household Food Access: Indicator Guide (Version 4). Washington, D.C.: FHI 360/FANTA.

Bohlool, B.B., Ladha, J.K., Garrity, D.P. & George, T. (1992). Biological nitrogen fixation for sustainable agriculture: A perspective. *Plant and Soil,* 141, 1-11.

Chamberlain, G. (1984). Panel Data. In Z. Griliches & M.D. Intriligator (Eds.), *Handbook of Econometrics* (pp. 1247-1318). Elsevier.

Chauhan, B.S., Mahajany, G., Sardanay, V., Timsina, J. & Jat, M.L. (2012). Productivity and sustainability of the rice–wheat cropping system in the Indo-Gangetic plains of the Indian subcontinent: problems, opportunities, and strategies. *Advances in Agronomy*, 117, 315–369.

Chung, K. (2012). An Introduction to Nutrition-Agriculture Linkages. MINAG/DE Research Report 72E. Maputo, Mozambique: Directorate of Economics, Ministry of Agriculture.

Dakora, F.D. & Keya, S.O. (1997). Contribution of legume nitrogen fixation to sustainable agriculture in Sub-Saharan Africa. *Soil Biology and Biochemistry,* 29(5), 809-817.

FAO. (1968). Food Composition Table for Use in Africa. Rome, Italy. Retrieved February 20, 2016 from http://www.fao.org/docrep/003/x6877e/x6877e00.htm

FAO. (2002). *The State of Food Insecurity in the World 2001*. Rome, Italy.

FAO. (2009). Summary of the FSN Forum Discussion No. 34: Food Security and Nutrition Security – What is the Problem and What is the Difference? Retrieved July 27, 2016 from http://www.fao.org/fsnforum/sites/default/files/files/34_Food_Security_Nutrition_Security/SUMMARY%20FSN%20difference%20%26%20problem.pdf

FAO. (2013). *Climate-Smart Agriculture: Sourcebook*. Rome, Italy.

FAO. (2016). 2016 International Year of Pulses – Frequently Asked Questions. Rome, Italy. Retrieved May 23, 2016 from http://www.fao.org/pulses-2016/faq/en/

Gillespie, S., Harris, L., & Kadiyala, S. (2012). The Agriculture-Nutrition Disconnect in India: What Do We Know? Discussion Paper 01187, International Food Policy Research Institute, Washington, D.C.

Hawkes, C., Turner, R., & Waage, J. (2012). *Current and Planned Research on Agriculture for Improved Nutrition: A Mapping and a Gap Analysis.* Report for the Department of International Development (DFID). Leverhulme Centre for Integrative Research on Agriculture and Health/University of Berdeen/Center for Sustainable International Development, London.

Headey, D., Chiu, A., & Kadiyala, S. (2011). *Agriculture's Role in the Indian Enigma: Help or Hindrance to the Undernutrition Crisis?* Discussion Paper 01085, International Food Policy Research Institute ,Washington, DC.

Herforth, A. & Harris, J. (2014). Understanding and Applying Primary Pathways and Principles. Brief #1. Improving Nutrition through Agriculture Technical Brief Series. USAID/Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) Project, Arlington, VA.

Hoddinott, J. & Yohannes, Y. (2002). *Dietary Diversity as a Food Security Indicator*. FCND Discussion Paper No. 136. International Food Policy Research Institute, Washington, D.C.

Howieson, J.G., O'Hara, G.W. & Carr, S.J. (2000). Changing roles for legumes in Mediterranean agriculture: developments from an Australian perspective. *Field Crops Research,* 65, 107-122.

IAPRI. (2012). The 2012 Rural Agricultural Livelihoods Survey (for Small and Medium Scale Holdings) Interviewer's Instruction Manual. Lusaka, Zambia.

IAPRI. (2015). The 2015 Rural Agricultural Livelihoods Survey (for Small and Medium Scale Holdings) Interviewer's Instruction Manual. Lusaka, Zambia.

Jahnke, H.E. (1982). Livestock Production Systems and Livestock Development in Tropical Africa. Kieler Wissenschaftsverlag Vauk, Kiel, Germany.

Jeranyama, P., Waddington, S.R., Hesterman, O.B. & Harwood, R.R. (2007). Nitrogen effects on maize yield following groundnut in rotation on smallholder farms in sub-humid Zimbabwe. *African Journal of Biotechnology*, 6(13), 1503–1508.

Jones, A., Shrinivas, A., & Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: findings from nationally representative data." *Food Policy,* 46, 1-12.

Kassie, M., Teklewold, H., Marenya, P., Jaleta, M., & Erenstein, O. (2015). Production risks and food security under alternative technology choices in Malawi: application of a multinomial endogenous switching regression. *Journal of Agricultural Economics*, 66(3), 640-659.

Kennedy, G., Ballard, T., & Dop, M. (2013). Guidelines for Measuring Household and Individual Dietary Diversity. FAO, Rome, Italy.

Leah, J., Pradel, W., Cole, D.C., Prain, G., Creed-Kanashiro, H., & Carrasco, M.V. (2012). Determinants of household food access among small farmers in the Andes: examining the path. *Public Health Nutrition,* 16(1), 136-145.

Lunze, L. & Ngongo, M. (2012). Potential nitrogen contribution of climbing bean to subsequent maize crop in rotation in South Kivu province of Democratic Republic of Congo. In A. Bationo, B. Waswa, J. Okeyo, F. Maina & J. Kihara (Eds.), *Innovations as Key to the Green Revolution in Africa* (pp. 677–681). Spring Science, Dordrecht, The Netherlands.

Manda, J., Alene, A., Gardebroek, C., Kassie, M., & Tembo, G. (2016). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: evidence from rural Zambia. *Journal of Agricultural Economics,* 67(1), 130-153.

Mundlak, Y. (1978). On the Pooling of Time Series and Cross Section Data. *Econometrica,* 64, 69–85

Murrell, D. (2016). Global Research and Funding Survey on Pulse Productivity and Sustainability. Global Pulse Confederation, Dubai. Retrieved May 23, 2016 from http://iyp2016.org/resources/documents/technical-reports/124-pulses-global-research-and-funding-survey/file

Ojiewo, C., Keatinge, D.J.D.H., Hughes, J., Tenkouano, A., Nair, R., Varshney, R., Siambi, M., Monyo, E., Ganga-Rao, NVPR., & Silim, S. (2015). The role of vegetables and legumes in assuring food, nutrition, and income security for vulnerable groups in Sub-Saharan Africa. *World Medical and Health Policy,* 7, 187-210.

Ruel, M.T., & Alderman, H. (2013). Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? *The Lancet*, 382(9891), 536-551.

Singh, I., Squire, L., & Strauss, J. (1986). *Agricultural Household Models: Extensions, Applications, and Policy*. The World Bank, Washington, DC.

Staiger, D. & Stock, J.H. (1997). Instrumental variables regression with weak instruments. *Econometrica,* 65(3), 557-586.

Swindale, A. & Bilinksy, P. (2006). Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide (Version 2). FHI 360/FANTA, Washington, D.C.

Tharanathan, R.N. & Mahadevamma, S. (2003). Grain legumes – a boon to human nutrition. *Trends in Food Science and Technology,* 14, 507-518.

Theirfelder, C., Cheesman, S., & Rusinamhodzi, L. (2012). A comparative analysis of conservation agriculture systems: benefits and challenges of rotations and intercropping in Zimbabwe." *Field Crops Research,* 137, 237-250.

USAID (United States Agency for International Development). (2013). Agriculture-to-Nutrition Pathways. Background document for the Agriculture and Nutrition Global Learning and Exchange Event, Bangkok, March 19-23, 2013.

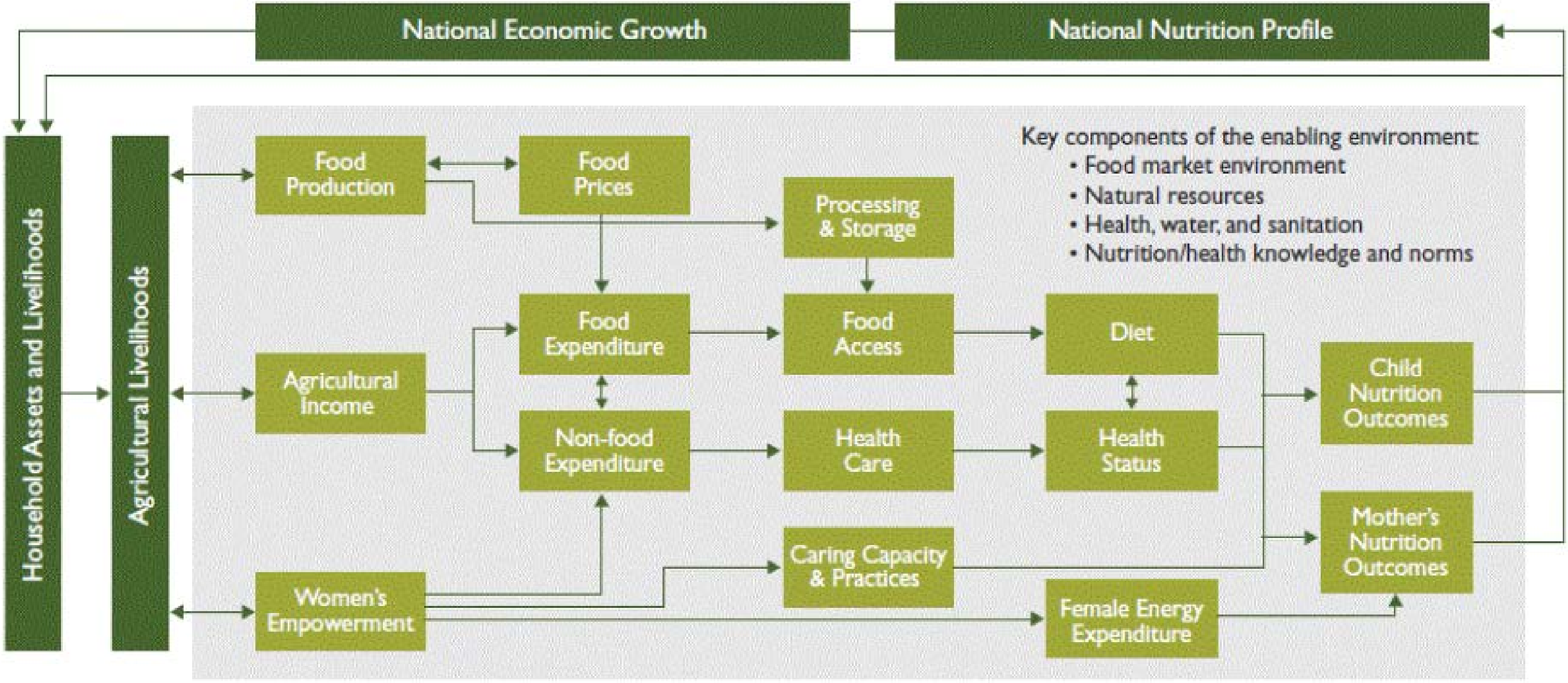
Webb, P. (2013). Impact pathways from agricultural research to improved nutrition and health: literature analysis and research priorities. FAO and WHO, Rome, Italy.

Wooldridge, J.M. (2010). Econometric Analysis of Cross Section and Panel Data, Second Edition. The MIT Press, Boston.

World Bank. (2007). *From Agriculture to Nutrition: Pathways, Synergies and Outcomes.* Agriculture and Rural Development Department. The World Bank, Washington, D.C.

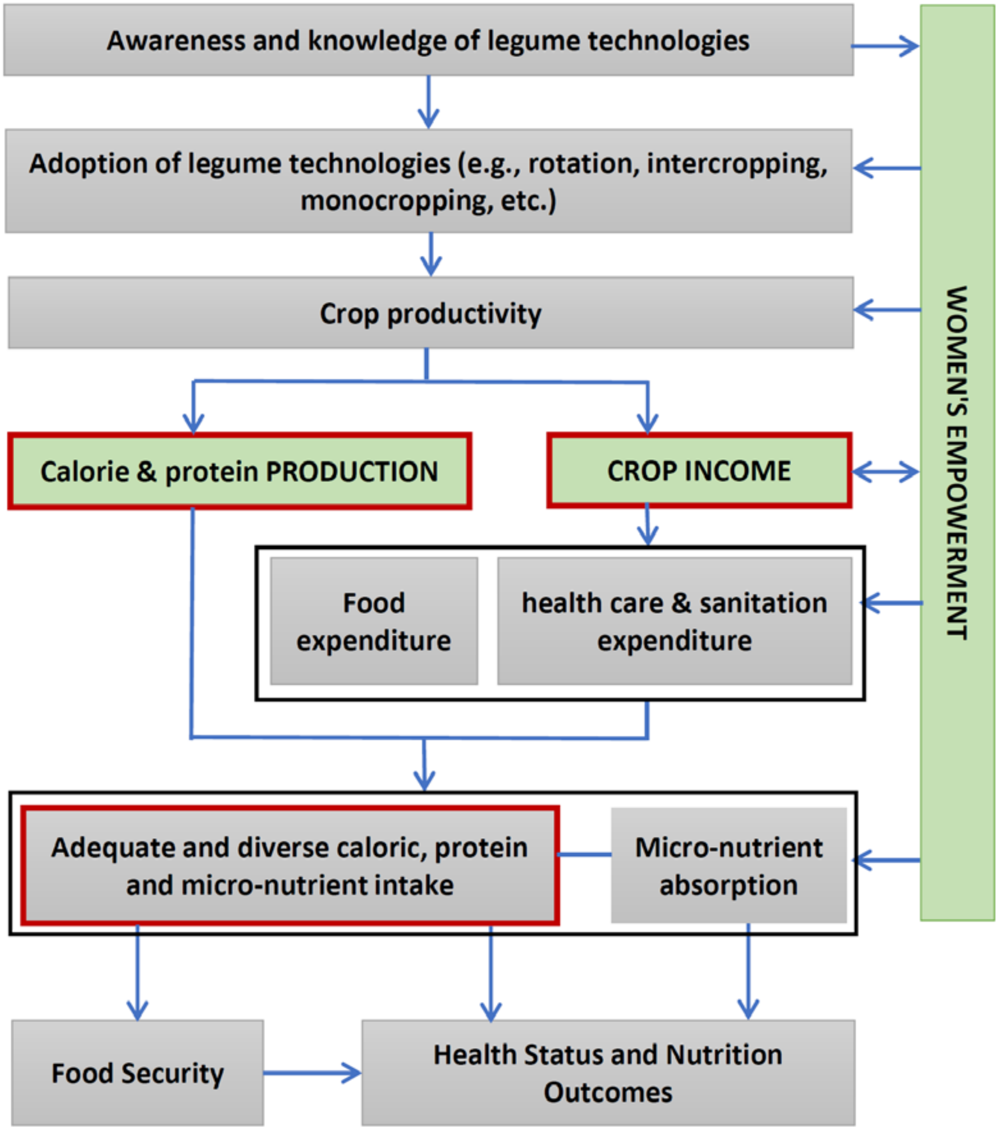
Wüstefeld, M. (2013). Food and Nutrition Security: UNSCN Meeting of the Minds – Nutrition Impacts of Food Systems. Retrieved July 27, 2016 from http://www.unscn.org/files/Annual_Sessions/UNSCN_Meetings_2013/Wustefeld_Final_MoM_FNS_concept.pdf

Figure 1: Agriculture-Nutrition Linkages - Conceptual Framework



Source: Herforth and Harris 2014.

Figure 2: Pathways of effects of legumes technology adoption on food security and nutritional status



Source: Authors' own compilation.

Figure 3. Timing of legume technology adoption vis-à-vis outcome variables

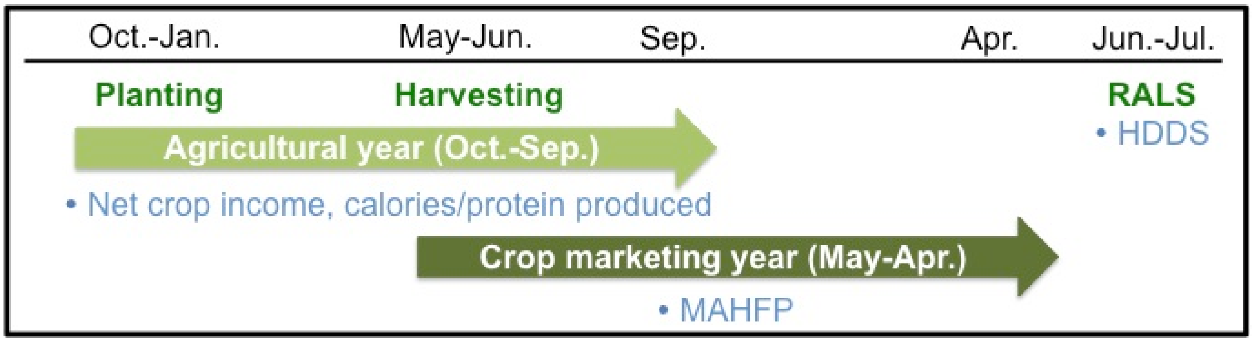
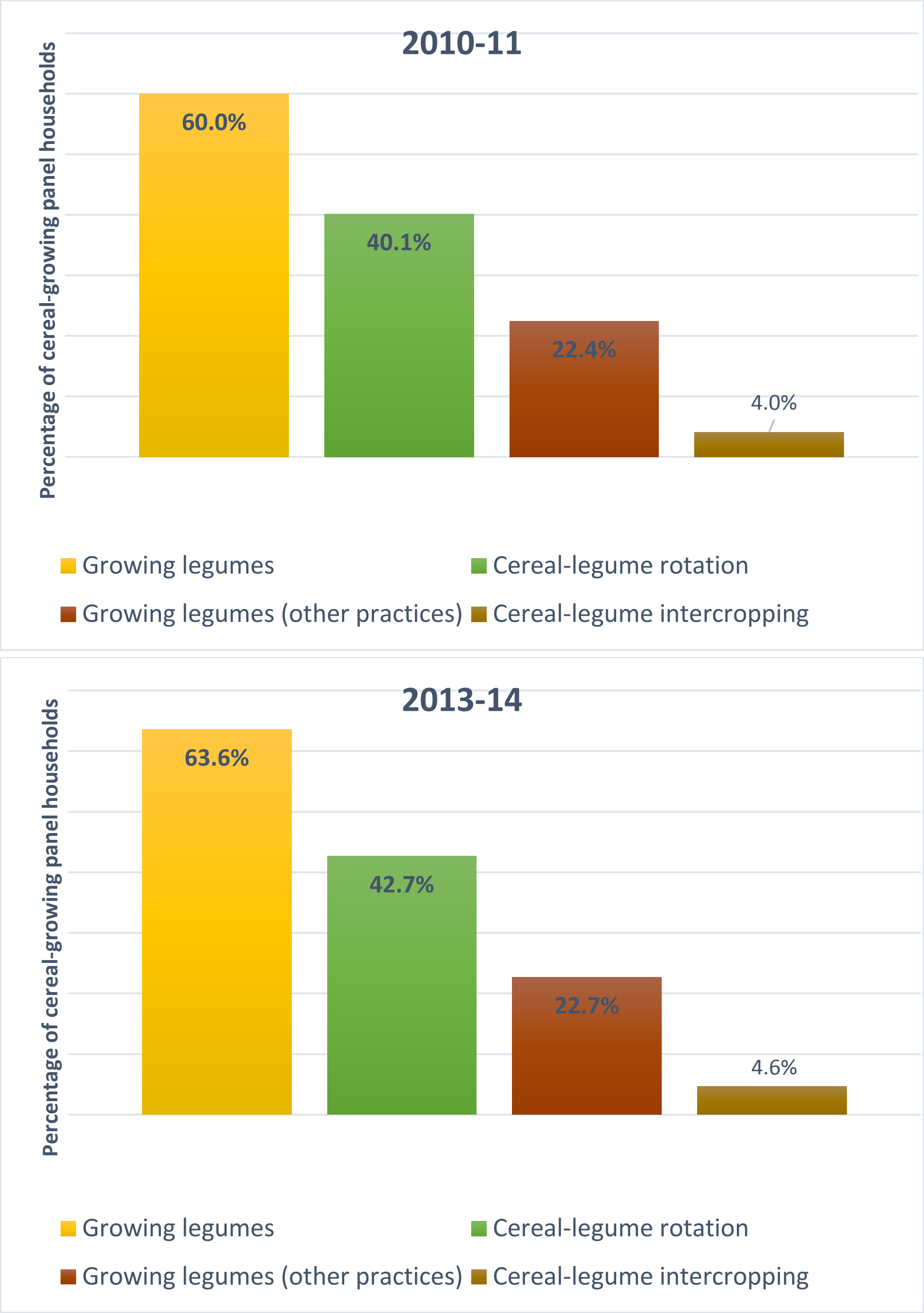


Figure 4. Importance of Cereals, Legumes and Legume Related Cropping Practices in Zambia: Comparison of the 2010/11 and 2013/14 Agricultural Years



Source: RALS 2012 and 2015.

Note: Reference population is panel households who grew a cereal crop (maize, sorghum, or millet) in both agricultural years (N=6,226). Percentages are weighted.

Table 1. Summary Statistics (2014/15 agricultural year values)

Variable	**Description**	**N**	**Mean**	**Std. Dev.**
Dependent Variables				
HDDS	Household dietary diversity score (0-12)	6225	5.71	2.09
MAHFP	Months of adequate household food provisions (0-12)	6226	10.42	2.14
net_crop_income	Net household crop income (real ZMW, 2014/15=100)	6226	4,779	6,474
tot_calories_PC_per_day	Total calories produced by household/capita/day	6226	5,913	9,075
tot_protein_PC_per_day	Total protein (grams) produced by household/capita/day	6226	158.46	256.82
Instrumental Variables				
intercropping_advice	=1 if household received advice on cereal-legume intercropping in the current ag. year or previously	6225	0.25	0.43
rotation_advice	=1 if household received advice on cereal-legume rotation in the current ag. year or previously	6225	0.53	0.5
percent_leg_in_sea	Percentage of other households in the standard enumeration area that grew legumes	6226	62.39	26.97
Explanatory Variables (variables marked by * are the key explanatory variables of interest)				
*cereal_legume_int	= 1 if household cereal-legume intercropped any plot	6226	0.05	0.21
*cereal_legume_rotation	= 1 if household rotated cereals and legumes between the previous and current agricultural year on any plot	6226	0.43	0.49
*legume_other	= 1 if household grew legumes in any form other than cereal-legume intercropping or rotation (e.g. legume monocropping, intercropping legumes and cassava, etc.)	6226	0.23	0.42
*tot_ha_plant_clint_leg	Total hectares planted to legumes on cereal-legume intercropped plots	6226	0.02	0.10
*tot_ha_plant_clrot	Total hectares cereal-legume rotated	6226	0.40	0.98
*tot_ha_plant_leg_other	Total hectares planted to other legume technologies	6226	0.15	0.34
num_members	Number of household members	6226	6.06	2.66
eduhead	Education level of household head (years)	6224	5.74	3.61
malehead	= 1 if household head is male	6226	0.75	0.43
age_HH_head	Age of household head (years)	6226	48.31	15.15
chief_related	= 1 if household head or head's spouse is related	6226	0.13	0.34

Variable	Description	N	Mean	Std. Dev.
	to the village chief			
landholdsz	Total landholding size (hectares)	6226	4.32	9.32
landoldszpp	Average landholding per household member (hectares)	6226	0.83	2.55
num_fields	Number of fields operated by household	6226	2.82	1.37
plotsz	Average plot size (hectares)	6226	1.68	4.39
radio	= 1 if household owns a radio	6226	0.58	0.49
cell_phone	= 1 if household owns a cell phone	6225	0.57	0.49
rural	=1 if household is rural	6226	0.95	0.21
dist_to_road	Distance (km) to nearest tarmac/tarred road	6226	27.38	33.42
dist_to_ag_camp	Distance (km) to nearest agricultural camp or block (extension) office	6226	17.14	22.17
dist_to_boma	Distance (km) to nearest market town	6226	39.45	30.69
assetall	Value of farm equipment (real ZMW, 2014/15=100) [a]	6226	12,233	143,670
tlu	Tropical Livestock Units owned [b]	6226	1.90	5.55
top_dress_price	District median farmgate price of top dressing fertilizer (real ZMW/kg, 2014/15=100)	6226	4.41	0.35
basal_price	District median farmgate price of basal dressing fertilizer (real ZMW/kg, 2014/15=100)	6226	4.42	0.44
dist_maize_price	District median maize producer price (real ZMW/kg, 2014/15=100)	6226	1.20	0.07
prov_groundnuts_price	Provincial median groundnuts producer price (real ZMW/kg, 2014/15=100)	6226	4.03	0.53
prov_mixed_beans_price	Provincial median mixed beans producer price (real ZMW/kg, 2014/15=100)	6226	4.53	0.75
prov_soybeans_price	Provincial median soybeans producer price (real ZMW/kg, 2014/15=100)	6226	2.56	1.08
mealie_meal_hungry_price	Provincial median price of commercial maize meal in the hungry season (Nov.-Apr.) (real ZMW/kg, 2014/15=100)	6226	2.68	0.09

Source: Authors' calculations based on the 2015 RALS.

Note: The reference population is panel households who grew a cereal crop in both the 2010/2011 and 2013/14 agricultural years. (N=6,226 in each of the two survey waves.)

a This variable includes ox-drawn ploughs, disc ploughs, harrows, cultivators, rippers, ridgers/weeders, planters, fitarelli (for zero tillage), tractors, hand driven tractors, scotch carts, wheel barrows, water pumps / treadle pumps, other irrigation equipment (e.g., irrigation pipes), knapsack sprayers, and boom sprayers. b TLU includes the following livestock types (conversion factors in parentheses): cattle (0.7), donkeys (0.5), pigs (0.2), and goats and sheep (0.1) (Jahnke 1982).

Table 2. Adoption of Legume Technologies in 2010/11 and 2013/14 Agricultural Years

Cereal-legume intercropping

		2013/14 (# HHs)		
		Adopted	Did not adopt	***Row Sum***
2010/11 (# HHs)	Adopted	71 (1.3%)	173 (2.7%)	244 (4.0%)
	Did not adopt	217 (3.3%)	5,765 (92.7%)	982 (96.0%)
	Column Sum	288 (4.6%)	5,938 (95.4%)	6,226

Cereal-legume rotation

		2013/14 (# HHs)		
		Adopted	Did not adopt	***Row Sum***
2010/11 (# HHs)	Adopted	1,589 (23.0%)	1,086 (17.2%)	2,675 (40.1%)
	Did not adopt	1,231 (19.7%)	2,320 (40.2%)	3,551 (59.9%)
	Column Sum	2,820 (42.7%)	3,406 (57.4%)	6,226

.

Other legume technologies

		2013/14 (# HHs)		
		Adopted	Did not adopt	***Row Sum***
2010/11 (# HHs)	Adopted	491 (7.2%)	1,059 (15.2%)	1,550 (22.4%)
	Did not adopt	958 (15.5%)	3,718 (62.1%)	4,676 (77.6%)
	Column Sum	1,449 (22.7%)	4,777 (77.3%)	6,226

Source: Authors' calculations based on the 2012 and 2015 RALS.
Note: Reference population is panel households that cultivated a cereal crop in both the 2010/2011 and 2013/2014 agricultural years (N=6,226). Weighted percentages in parentheses.

Table 3. Summary of Main Regression Results for the Effects of Cereal-Legume Intercropping on Household Welfare

Treatment variable:	**Binary (=1 if HH cereal-legume intercropped)**					**Continuous (total hectares cereal-legume intercropped)**				
Estimator:	OLS/POLS Coef.	2SLS Coef. †	FE Coef.	CRE Coef.	CRE-NB APE^{a}	OLS/POLS Coef.	2SLS Coef. †	FE Coef.	CRE Coef.	CRE-NB APE^{a}
<u>*Outcome Variable*</u>:										
HDDS	0.110	9.410***		0.210	0.0629	0.592*	13.02		0.685	0.750**
	(0.148)	(3.063)		(0.243)	(0.166)	(0.344)	(8.467)		(0.431)	(0.374)
MAHFP	-0.0598	-0.0331	-0.0791		--^{b}	0.167	-7.886*	-0.152		--^{b}
	(0.139)	(2.064)	(0.164)			(0.184)	(4.476)	(0.222)		
Net crop income	134.1	6,727	287.6			-1,337	10,874	958.3		
(ZMW)	(271.1)	(4,634)	(312.9)			(817.4)	(8,478)	(966.8)		
Calorie production/	-877.2**	3,748	98.12			-3,747***	-10,485	-981.3		
capita/day	(367.8)	(7,528)	(375.2)			(759.3)	(13,711)	(691.4)		
Protein production/	-25.36***	76.04	0.267			-112.7***	-556.0	-35.38**		
capita/day (grams)	(9.593)	(223.4)	(9.197)			(21.56)	(403.5)	(17.96)		

Source: Authors' calculations.

Note: * $p<0.1$; ** $p<0.05$; *** $p<0.01$. n=12,442 for all models except HDDS (n=6,221). Standard errors are in parentheses and are clustered at the village level for HDDS and at the household level for the other outcome variables. APE = average partial effect. ^{a}All NB models assume a quadratic variance function. ^{b}CRE-NB did not converge. † Hausman test results suggest that we reject the null hypothesis that cereal-legume intercropping and rotation and other legume technologies are jointly exogenous to each outcome variable (p<0.10).

Table 4: Summary of Main Regression Results for the Effects of Cereal-Legume Rotation on Household Welfare

Treatment variable:	**Binary (=1 if HH cereal-legume rotated)**					**Continuous (total hectares cereal-legume rotated)**				
Estimator:	OLS/POLS Coef.	2SLS Coef. †	FE Coef.	CRE Coef.	CRE-NB APE^{a}	OLS/POLS Coef.	2SLS Coef. †	FE Coef.	CRE Coef.	CRE-NB APE^{a}

Outcome Variable:										
HDDS	0.183**	0.826		0.135	0.107	0.118***	2.714**		0.0563	0.0404
	(0.0900)	(0.616)		(0.143)	(0.0933)	(0.0305)	(1.073)		(0.0579)	(0.0498)
MAHFP	0.148**	2.766***	0.0476		--[b]	0.0908***	2.523***	0.0479**		--[b]
	(0.0639)	(0.357)	(0.0932)			(0.0178)	(0.661)	(0.0244)		
Net crop income	-143.0	615.2	-617.5***			1,619***	780.9	583.6***		
(ZMW)	(151.1)	(726.0)	(198.7)			(179.2)	(1,280)	(220.7)		
Calorie production/	562.4**	6,146***	-360.5			2,247***	5,790***	1,088***		
capita/day	(236.7)	(1,155)	(287.3)			(249.7)	(1,952)	(296.6)		
Protein production/	34.86***	236.7***	9.171			71.32***	231.9***	37.64***		
capita/day (grams)	(6.291)	(35.31)	(7.709)			(6.713)	(56.86)	(7.783)		

Source: Authors' calculations.

Note: * $p<0.1$; ** $p<0.05$; *** $p<0.01$. n=12,442 for all models except HDDS (n=6,221). Standard errors are in parentheses and are clustered at the village level for HDDS and at the household level for the other outcome variables. APE = average partial effect. [a]All NB models assume a quadratic variance function. [b]CRE-NB did not converge. † Hausman test results suggest that we reject the null hypothesis that cereal-legume intercropping and rotation are jointly exogenous to each outcome variable (p<0.10).

Table 5: Summary of Main Regression Results for the Effects of Other Legume Technologies on Household Welfare

Treatment variable:	**Binary (=1 if HH adopted another legume technology)**					**Continuous (total hectares planted to other legume technologies)**				
Estimator:	OLS/POLS Coef.	2SLS Coef. †	FE Coef.	CRE Coef.	CRE-NB APE[a]	OLS/POLS Coef.	2SLS Coef. †	FE Coef.	CRE Coef.	CRE-NB APE[a]
Outcome Variable:										
HDDS	0.196**	-5.977**		0.260*	0.170*	0.185**	-8.065*		0.142	0.115
	(0.0890)	(2.375)		(0.139)	(0.0911)	(0.0876)	(4.206)		(0.143)	(0.131)
MAHFP	0.0816	-1.274	-0.0634		--b	0.0939	0.583	-0.0898		--b
	(0.0706)	(1.733)	(0.0977)			(0.0600)	(2.130)	(0.0807)		

Net crop income (ZMW)	-259.7	-3,152	-485.2**	2,184***	-2,065	1,421***
	(173.7)	(3,801)	(207.3)	(292.9)	(4,294)	(295.5)
Calorie production/ capita/day	283.7	-4,655	-463.3*	1,997***	-240.7	1,130***
	(286.9)	(5,911)	(275.4)	(326.4)	(6,090)	(293.8)
Protein production/ capita/day (grams)	25.72***	-186.1	7.560	79.30***	-40.06	54.77***
	(7.390)	(175.6)	(6.930)	(9.157)	(174.5)	(8.138)

Source: Authors' calculations.

Note: * $p<0.1$; ** $p<0.05$; *** $p<0.01$. n=12,442 for all models except HDDS (n=6,221). Standard errors are in parentheses and are clustered at the village level for HDDS and at the household level for the other outcome variables. APE = average partial effect. [a]All NB models assume a quadratic variance function. [b]CRE-NB did not converge. † Hausman test results suggest that we reject the null hypothesis that cereal-legume intercropping and rotation are jointly exogenous to each outcome variable (p<0.10).

Table 6: Regression Results for the Effects of Crop Income and Calorie Production on HDDS and MAHFP

Dependent variable:	HDDS		MAHFP	
Estimator:	OLS	CRE-NB	POLS	FE
	Coef.	APE[a]	Coef.	Coef.
Explanatory Variables				
net_harv	.00001225*	.00000830	.0000291***	.0000124**
	(.00000657)	(.00000917)	(.00000454)	(.00000592)
tot_calories_PC_per_day	.0000165***	.00000457	.00000775**	.0000000617
	(.00000486)	(.00000542)	(.00000325)	(.00000403)
Num_members	0.0502***	0.000894	-0.0199*	-0.0781***
	(0.0139)	(0.0351)	(0.0106)	(0.0257)
eduhead	0.0961***	0.0230	0.0446***	0.0271
	(0.0109)	(0.0263)	(0.00696)	(0.0192)
malehead	-0.204**	0.881***	0.157**	0.559**
	(0.0815)	(0.302)	(0.0621)	(0.218)
age_HH_head	0.0124	-0.0338**	-0.0151	0.0490
	(0.0129)	(0.0136)	(0.0102)	(0.0383)
age_HH_head_squared	-0.000150		0.000100	-0.000554
	(0.000119)		(.0000998)	(0.000359)
chief_related	0.146	0.473***	-0.0132	-0.147
	(0.0990)	(0.162)	(0.0722)	(0.120)
landholdsz	0.0100**	0.00855	-0.00945**	-0.00135
	(0.00488)	(0.0101)	(0.00453)	(0.00531)
landholdszpp	-0.0425***	-0.0163	0.0295*	0.00305
	(0.0154)	(0.0330)	(0.0164)	(0.0149)
radio	0.438***	0.331***	0.337***	0.137*
	(0.0708)	(0.102)	(0.0506)	(0.0766)
cell_phone	0.449***	0.203	0.229***	0.00897
	(0.0737)	(0.124)	(0.0527)	(0.0848)
dist_to_road	-0.00183	0.000981	0.000334	-.00000664
	(0.00138)	(0.00373)	(0.00118)	(0.00243)
dist_to_boma	-0.00291**	0.000978	0.00154	0.000847
	(0.00140)	(0.00313)	(0.00115)	(0.00255)
assetall	.000000432*	.0000000615	.0000000807	.00000000727
	(.000000239)	(.000000282)	(.0000000694)	(.000000128)
tlu	0.0272***	0.0145	0.0173***	0.0194***
	(0.00626)	(0.0110)	(0.00424)	(0.00725)
num_fields	0.0139	0.0533	0.0309*	0.00452
	(0.0290)	(0.0422)	(0.0186)	(0.0282)
mealie_meal_hungry_pr	-8.425***	-10.82***	0.716	1.213

Dependent variable:	HDDS		MAHFP	
Estimator:	OLS	CRE-NB	POLS	FE
	Coef.	APE[a]	Coef.	Coef.
Explanatory Variables				
	(1.725)	(2.002)	(10.16)	(10.06)
rural	-0.386*	-0.297	-0.295**	
	(0.203)	(0.191)	(0.122)	
year_2015			-0.604	-0.888
			(7.295)	(7.225)
Constant	26.68***		9.645	6.818
	(4.815)		(19.09)	(20.61)
N	6,221	6,221	12,442	12,442
R-squared	0.265	--	0.214	0.109

Source: Authors' calculations.

Note: * p<0.1; ** p<0.05; *** p<0.01. Standard errors in parentheses. APE = average partial effect.

[a] Assumes quadratic variance function.

APPENDIX

Table A1. First Stage Regression Results for Binary Treatment Variable Models

	Dependent (endogenous) variable:					
	Cross-Sectional Data (OLS) [for HDDS (2015 RALS only)]			Panel Data (POLS) [for all other outcome variables]		
Explanatory Variables	Intercropping (=1)	Rotation (=1)	Other (=1)	Intercropping (=1)	Rotation (=1)	Other (=1)
IV: intercropping_advice	0.0514***	0.00996	-0.00770	0.0401***	0.00352	-0.00172
	(0.0110)	(0.0196)	(0.0169)	(0.00816)	(0.0157)	(0.0127)
IV: rotation_advice	-0.0332***	0.126***	-0.0621***	-0.0294***	0.0802***	-0.0288**
	(0.00869)	(0.0182)	(0.0164)	(0.00559)	(0.0130)	(0.0112)
IV: percent_leg_in_sea	0.000843***	0.00444***	0.00107***	0.000658***	0.00428***	0.00108***
	(0.000238)	(0.000335)	(0.000298)	(0.000116)	(0.000203)	(0.000173)
Num_members	0.00134	0.00641**	-0.00448	0.00224**	0.00459*	-0.00308
	(0.00144)	(0.00322)	(0.00286)	(0.00106)	(0.00234)	(0.00204)
eduhead	0.00122	-0.00387*	0.00265	0.000952	-0.000850	0.00235
	(0.000999)	(0.00229)	(0.00218)	(0.000708)	(0.00170)	(0.00146)
malehead	-0.00695	-0.0428**	-0.0334*	-0.00818	-0.0496***	-0.0240*
	(0.00956)	(0.0201)	(0.0188)	(0.00711)	(0.0147)	(0.0126)
age_HH_head	0.00155	0.00652**	-0.00461*	0.00131	0.00738***	-0.00410**
	(0.00142)	(0.00298)	(0.00274)	(0.00109)	(0.00220)	(0.00197)
age_HH_head_squared	-1.40e-05	-5.18e-05*	4.41e-05*	-1.09e-05	-5.69e-05***	3.79e-05**
	(1.32e-05)	(2.75e-05)	(2.57e-05)	(1.05e-05)	(2.08e-05)	(1.84e-05)
chief_related	0.0206	-0.0393	0.0352	0.0259***	-0.0352**	0.0139
	(0.0134)	(0.0247)	(0.0225)	(0.00862)	(0.0167)	(0.0151)
plotsz	0.00113	-0.00149	-0.00305	0.00352**	-0.000722	-0.00280
	(0.00101)	(0.00246)	(0.00194)	(0.00176)	(0.00198)	(0.00206)
landholdsz	-0.000319	0.000542	0.000945	-0.000543	0.00164	0.000781
	(0.000431)	(0.00148)	(0.00129)	(0.000707)	(0.00134)	(0.00140)

	Dependent (endogenous) variable:					
	Cross-Sectional Data (OLS) [for HDDS (2015 RALS only)]			Panel Data (POLS) [for all other outcome variables]		
Explanatory Variables	Intercropping (=1)	Rotation (=1)	Other (=1)	Intercropping (=1)	Rotation (=1)	Other (=1)
landholdszpp	-0.00161	-3.40e-05	0.000319	-0.00267	-0.00422	-0.000747
	(0.00142)	(0.00559)	(0.00348)	(0.00174)	(0.00369)	(0.00369)
radio	0.00132	0.0218	0.0320**	-0.00466	0.0167	0.0219**
	(0.00802)	(0.0167)	(0.0153)	(0.00546)	(0.0118)	(0.0101)
cell_phone	-0.00311	0.0360*	-0.0172	0.00571	0.0168	-0.00757
	(0.00949)	(0.0194)	(0.0158)	(0.00601)	(0.0122)	(0.0106)
dist_to_road	0.000812**	7.78e-05	-0.000258	0.000738***	-0.000329**	-0.000135
	(0.000316)	(0.000264)	(0.000225)	(0.000135)	(0.000161)	(0.000139)
dist_to_ag_camp	-0.000189	-6.06e-05	-0.000416	-8.28e-06	-0.000248	-4.73e-06
	(0.000185)	(0.000429)	(0.000353)	(0.000116)	(0.000238)	(0.000205)
dist_to_boma	-0.000451**	-0.000548	0.000524*	-0.000497***	-0.000190	0.000114
	(0.000211)	(0.000348)	(0.000307)	(0.000119)	(0.000202)	(0.000182)
assetall	-7.12e-09	5.01e-08***	-9.99e-09	-1.09e-08*	2.23e-08*	-4.82e-09
	(6.09e-09)	(1.30e-08)	(1.23e-08)	(6.08e-09)	(1.19e-08)	(8.56e-09)
tlu	0.00124	0.00521***	-0.00155	0.000314	0.00493***	-0.00179***
	(0.000794)	(0.00119)	(0.00104)	(0.000314)	(0.000808)	(0.000636)
num_fields	-0.00929**	0.0776***	0.0617***	-0.00973***	0.0717***	0.0644***
	(0.00385)	(0.00667)	(0.00663)	(0.00195)	(0.00410)	(0.00415)
top_cost	0.0472*	0.0683	-0.0942**	0.109***	0.0694***	-0.0808***
	(0.0263)	(0.0467)	(0.0369)	(0.0186)	(0.0264)	(0.0262)
basal_cost	0.00338	-0.000751	0.00950	-0.0622***	-0.0419*	0.0293
	(0.0126)	(0.0358)	(0.0239)	(0.0131)	(0.0221)	(0.0220)
mealie_meal_hungry_price	0.212***	0.0436	-0.0303	0.184***	0.142***	-0.130***
	(0.0731)	(0.109)	(0.0869)	(0.0261)	(0.0477)	(0.0430)
rural	-0.0148	0.00622	-0.0445	0.00190	0.0293	-0.0362
	(0.0239)	(0.0500)	(0.0336)	(0.0129)	(0.0273)	(0.0228)

	Dependent (endogenous) variable:					
	Cross-Sectional Data (OLS) [for HDDS (2015 RALS only)]			Panel Data (POLS) [for all other outcome variables]		
Explanatory Variables	Intercropping (=1)	Rotation (=1)	Other (=1)	Intercropping (=1)	Rotation (=1)	Other (=1)
year_2015				-0.107***	-0.107***	0.0831***
				(0.0172)	(0.0314)	(0.0278)
Constant	-0.805***	-0.744**	0.647**	-0.609***	-0.711***	0.637***
	(0.247)	(0.315)	(0.278)	(0.0929)	(0.152)	(0.145)
N	6,221	6,221	6,221	12,442	12,442	12,442
R-squared	0.056	0.176	0.069	0.058	0.154	0.070
Partial F-stat. (excluded IVs)	**9.29**	**95.97**	**9.19**	**18.04**	**175.64**	**14.96**

Source: Authors' calculations.

Note: * *p*<0.1; ** *p*<0.05; *** *p*<0.01. Standard errors in parentheses.

Table A2. First Stage Regression Results for Continuous Treatment Variable Models

Explanatory Variables	Dependent (endogenous) variable:					
	Cross-Sectional Data (OLS) [for HDDS (2015 RALS only)]			Panel Data (POLS) [for all other outcome variables]		
	Intercropping (ha)	Rotation (ha)	Other (ha)	Intercropping (ha)	Rotation (ha)	Other (ha)
IV: intercropping_advice	0.0233***	0.0847*	-0.000585	0.0212***	0.0697**	0.00382
	(0.00590)	(0.0438)	(0.0118)	(0.00445)	(0.0288)	(0.00920)
IV: rotation_advice	-0.0104***	0.130***	0.00670	-0.0104***	0.0704***	-1.59e-06
	(0.00371)	(0.0360)	(0.0109)	(0.00228)	(0.0202)	(0.00693)
IV: percent_leg_in_sea	0.000364***	0.00530***	0.00173***	0.000298***	0.00470***	0.00158***
	(0.000103)	(0.000631)	(0.000240)	(0.0000495)	(0.000313)	(0.000117)
Num_members	0.000845	0.0152*	-0.000769	0.00106**	0.0102*	-0.000641
	(0.000648)	(0.00864)	(0.00192)	(0.000529)	(0.00529)	(0.00131)
eduhead	0.000593	-0.00134	-3.29e-06	0.000588**	0.00178	8.88e-05
	(0.000480)	(0.00390)	(0.00153)	(0.000286)	(0.00240)	(0.000983)
malehead	-0.00200	-0.0540*	0.0106	-0.00236	-0.0266	0.0117*
	(0.00344)	(0.0320)	(0.00933)	(0.00316)	(0.0197)	(0.00695)
age_HH_head	0.000504	0.00462	-0.00216	0.000372	0.00621*	-0.00134
	(0.000515)	(0.00502)	(0.00192)	(0.000525)	(0.00345)	(0.00119)
age_HH_head_squared	-4.40e-06	-3.26e-05	2.02e-05	-2.73e-06	-4.44e-05	1.21e-05
	(4.83e-06)	(4.68e-05)	(1.70e-05)	(4.88e-06)	(3.32e-05)	(1.10e-05)
chief_related	0.00600	-0.0265	-0.000215	0.00884**	-0.0226	-0.00601
	(0.00494)	(0.0439)	(0.0155)	(0.00429)	(0.0251)	(0.0103)
plotsz	0.00102	0.00552	-0.00265*	0.00192	0.00232	-0.00451**
	(0.000879)	(0.00981)	(0.00155)	(0.00117)	(0.0103)	(0.00185)
landholdsz	2.72e-05	0.0154***	0.00277**	0.000161	0.0196***	0.00545***
	(0.000226)	(0.00567)	(0.00122)	(0.000493)	(0.00632)	(0.00144)

	Dependent (endogenous) variable:					
	Cross-Sectional Data (OLS) [for HDDS (2015 RALS only)]			Panel Data (POLS) [for all other outcome variables]		
Explanatory Variables	Intercropping (ha)	Rotation (ha)	Other (ha)	Intercropping (ha)	Rotation (ha)	Other (ha)
landholdszpp	-0.00133	-0.0336***	-0.00141	-0.00176*	-0.0306**	-0.00440
	(0.00103)	(0.0128)	(0.00243)	(0.000996)	(0.0132)	(0.00281)
radio	0.00540	0.0839***	0.0166*	0.00125	0.0475***	0.0144**
	(0.00481)	(0.0276)	(0.00925)	(0.00224)	(0.0154)	(0.00608)
cell_phone	-0.00211	0.110***	0.0192*	0.00203	0.0746***	0.00981
	(0.00489)	(0.0312)	(0.0104)	(0.00267)	(0.0173)	(0.00683)
dist_to_road	0.000348**	0.00130**	-4.48e-05	0.000299***	0.000254	-0.000156**
	(0.000141)	(0.000534)	(0.000173)	(5.75e-05)	(0.000245)	(7.83e-05)
dist_to_ag_camp	-5.17e-05	0.000750	-0.000244	2.35e-06	0.000312	-8.16e-05
	(9.74e-05)	(0.000889)	(0.000278)	(5.36e-05)	(0.000393)	(0.000134)
dist_to_boma	-0.000153*	-0.000859	0.000475**	-0.000152***	-0.000290	0.000311***
	(8.26e-05)	(0.000590)	(0.000233)	(5.68e-05)	(0.000293)	(0.000120)
assetall	-2.27e-09	2.44e-07*	2.40e-08	-5.58e-09*	9.86e-08*	7.20e-09
	(2.91e-09)	(1.31e-07)	(1.86e-08)	(3.17e-09)	(5.47e-08)	(7.17e-09)
tlu	0.000830*	0.0202***	0.000286	0.000364*	0.0156***	-0.000234
	(0.000494)	(0.00673)	(0.00101)	(0.000207)	(0.00420)	(0.000518)
num_fields	-0.00505***	0.0475***	0.0733***	-0.00504***	0.0420***	0.0710***
	(0.00144)	(0.0126)	(0.00707)	(0.000885)	(0.00773)	(0.00366)
top_cost	0.0146	-0.0161	-0.0603*	0.0371***	0.0918**	0.000848
	(0.00903)	(0.0600)	(0.0317)	(0.00685)	(0.0382)	(0.0147)
basal_cost	0.00179	0.0641	0.0468	-0.0239***	-0.0762**	0.0293**
	(0.00434)	(0.0424)	(0.0284)	(0.00528)	(0.0304)	(0.0122)
mealie_meal_hungry_price	0.0902***	0.0421	0.261***	0.0703***	0.0665	0.131***
	(0.0329)	(0.211)	(0.0879)	(0.00904)	(0.0667)	(0.0295)
rural	-0.000522	0.0601	0.00404	0.00666*	0.0944***	0.00553
	(0.00772)	(0.0549)	(0.0130)	(0.00354)	(0.0262)	(0.00990)

	Dependent (endogenous) variable:					
	Cross-Sectional Data (OLS) [for HDDS (2015 RALS only)]			Panel Data (POLS) [for all other outcome variables]		
Explanatory Variables	Intercropping (ha)	Rotation (ha)	Other (ha)	Intercropping (ha)	Rotation (ha)	Other (ha)
year_2015				-0.0450***	-0.0454	-0.0685***
				(0.00663)	(0.0430)	(0.0179)
Constant	-0.334***	-0.934	-0.803***	-0.223***	-0.760***	-0.573***
	(0.109)	(0.642)	(0.253)	(0.0336)	(0.233)	(0.101)
N	6,221	6,221	6,221	12,442	12,442	12,442
R-squared	0.047	0.100	0.156	0.037	0.094	0.176
Partial F-stat. (excluded IVs)	**6.54**	**33.52**	**18.22**	**18.70**	**91.27**	**62.14**

Source: Authors' calculations.

Note: * *p*<0.1; ** *p*<0.05; *** *p*<0.01. Standard errors in parentheses.

Table A3. Select full FE regression results

Outcome Variable:	MAHFP		Net Crop Income (ZMW)		Calorie production/ capita/day		Protein production/capita/day	
Treatment Variable:	Binary	Continuous	Binary	Continuous	Binary	Continuous	Binary	Continuous
Explanatory Variables								
Cereal-legume Intercropping	-0.0791	-0.152	287.6	958.3	98.12	-981.3	0.267	-35.38**
	(0.164)	(0.222)	(312.9)	(966.8)	(375.2)	(691.4)	(9.197)	(17.96)
Cereal-legume Rotation	0.0476	0.0479**	-617.5***	583.6***	-360.5	1,088***	9.171	37.64***
	(0.0932)	(0.0244)	(198.7)	(220.7)	(287.3)	(296.6)	(7.709)	(7.783)
Other Legume Tech.	-0.0634	-0.0898	-485.2**	1,421***	-463.3*	1,130***	7.560	54.77***
	(0.0977)	(0.0807)	(207.3)	(295.5)	(275.4)	(293.8)	(6.930)	(8.138)
Num_members	-0.0770***	-0.0773***	64.17	54.07	-1,128***	-1,145***	-29.83***	-30.39***
	(0.0247)	(0.0247)	(57.39)	(56.70)	(110.7)	(110.4)	(2.969)	(2.949)
eduhead	0.0290	0.0290	66.98*	61.84*	69.58	64.11	1.128	0.882
	(0.0193)	(0.0193)	(37.29)	(37.02)	(50.76)	(50.07)	(1.443)	(1.423)
malehead	0.571***	0.573***	151.0	183.4	-291.6	-207.0	-23.85	-20.74
	(0.218)	(0.218)	(479.5)	(472.2)	(763.2)	(760.3)	(29.89)	(29.64)
age_HH_head	0.0488	0.0492	128.8**	115.6**	325.2***	307.4***	8.613***	8.091***
	(0.0383)	(0.0383)	(51.74)	(51.64)	(96.28)	(96.61)	(2.577)	(2.571)
age_HH_head_squared	-0.000550	-0.000554	-1.017**	-0.858*	-2.981***	-2.778***	-0.0779***	-0.0725***
	(0.000359)	(0.000359)	(0.452)	(0.453)	(0.826)	(0.831)	(0.0219)	(0.0218)
chief_related	-0.154	-0.153	-123.8	-142.6	4.850	-12.54	-3.929	-5.230

Outcome Variable:	MAHFP		Net Crop Income (ZMW)		Calorie production/ capita/day		Protein production/capita/day	
Treatment Variable:	Binary	Continuous	Binary	Continuous	Binary	Continuous	Binary	Continuous
Explanatory Variables								
	(0.120)	(0.120)	(244.5)	(243.4)	(359.6)	(360.0)	(9.402)	(9.380)
landholdsz	0.00257	0.00235	94.62***	80.93***	213.3	197.2	5.665	5.102
	(0.00616)	(0.00627)	(32.16)	(30.45)	(134.8)	(134.2)	(3.540)	(3.506)
landholdszpp	0.00584	0.00646	-77.26	-70.13	70.85	83.42	1.536	2.011
	(0.0164)	(0.0164)	(90.46)	(85.36)	(295.2)	(290.8)	(7.320)	(7.171)
plotsz	-0.00983	-0.0100	-22.06	-9.061	-543.0*	-532.6	-14.39*	-14.13*
	(0.0108)	(0.0109)	(50.84)	(47.67)	(327.3)	(325.6)	(8.522)	(8.450)
radio	0.139*	0.141*	175.1	133.3	345.0	305.9	9.282	7.683
	(0.0767)	(0.0765)	(139.8)	(137.9)	(229.1)	(225.9)	(6.071)	(5.947)
cell_phone	0.0105	0.00833	96.45	87.08	-29.17	-51.04	1.107	0.286
	(0.0848)	(0.0849)	(150.1)	(150.8)	(251.1)	(250.0)	(6.668)	(6.606)
dist_to_road	0.00049	0.000497	6.069	6.239	2.432	2.799	-0.146	-0.152
	(0.00243	(0.00243)	(4.751)	(4.760)	(5.042)	(5.009)	(0.152)	(0.151)
dist_to_ag_camp	-	-	-2.795	-2.483	2.400	2.706	0.0302	0.0401
	(0.00140	(0.00140)	(3.272)	(3.179)	(4.304)	(4.014)	(0.103)	(0.0932)
dist_to_boma	0.00170	0.00164	7.033	6.515	8.637**	7.816*	0.278**	0.263**
	(0.00257	(0.00258)	(4.521)	(4.553)	(4.403)	(4.415)	(0.112)	(0.112)
assetall	8.88e-09	-7.69e-09	0.00144	0.00115	0.00190	0.00143	5.67e-05	4.24e-05
	(1.33e-	(1.32e-07)	(0.00112)	(0.00103)	(0.00228)	(0.00216)	(6.00e-	(5.66e-05)
tlu	0.0209**	0.0205***	138.5***	126.0***	227.0***	208.8***	6.760***	6.234***
	(0.00713	(0.00713)	(33.00)	(33.18)	(60.89)	(60.72)	(1.772)	(1.746)
num_fields	0.0105	0.0140	1,097***	916.3***	722.8***	553.0***	13.58***	9.867**
	(0.0314)	(0.0293)	(87.87)	(79.76)	(179.7)	(177.5)	(4.800)	(4.751)
top_cost	4.454*	4.504*	19,250***	19,473***	11,232***	11,762***	301.1***	311.8***
	(2.690)	(2.690)	(3,767)	(3,766)	(2,913)	(2,977)	(74.30)	(76.36)
basal_cost	-1.281	-1.280	-4,573	-4,601	-1,895	-2,014	-96.72**	-101.4***

Outcome Variable:	MAHFP		Net Crop Income (ZMW)		Calorie production/ capita/day		Protein production/capita/day	
Treatment Variable:	Binary	Continuous	Binary	Continuous	Binary	Continuous	Binary	Continuous
Explanatory Variables								
	(1.283)	(1.285)	(2,861)	(2,845)	(1,725)	(1,723)	(38.06)	(37.99)
mealie_meal_hungry_pr	54.40	55.46	267,925***	266,579***	239,538**	240,860***	5,501***	5,425***
	(42.36)	(42.36)	(66,163)	(66,695)	(57,658)	(58,403)	(1,525)	(1,543)
year_2015	-37.51	-38.25	-	-184,290***	-	-166,657***	-	-3,751***
	(29.43)	(29.43)	(45,684)	(46,047)	(39,705)	(40,236)	(1,050)	(1,063)
Constant	-116.5	-118.9	-	-616,611***	-	-535,962***	-	-12,005***
	(96.02)	(96.01)	(150,177)	(151,455)	(125,929)	(127,652)	(3,314)	(3,357)
N	12,442	12,442	12,442	12,442	12,442	12,442	12,442	12,442
R-squared	0.111	0.111	0.159	0.170	0.119	0.131	0.109	0.133

Source: Authors' calculations.

Note: * $p<0.1$; ** $p<0.05$; *** $p<0.01$. Standard errors in parentheses.

www.feedthefuture.gov