Impact of the Fall Armyworm on the Nutrition Security of Children and Mothers in Eastern Uganda

by Brian Chisanga, Menale Kassie, and Erwin Bulte

IMPACT OF THE FALL ARMYWORM ON THE NUTRITION SECURITY OF CHILDREN AND MOTHERS IN EASTERN UGANDA

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Abstract

This paper explores the impact of FAW infestation on the food security of children and mothers in Eastern Uganda using an exogenous treatment effect model. We also test our exogeneity assumption as a robsutness check. We find a negative impact of FAW on mothers' and children's dietary diversity under five years of age. Further, FAW infestation caused maize yields and sales to fall ignificantly, but increased insecticides use. These findings suggest that FAW infestation worsens the already precarious food security and nutrition status, especially for children under five years. Policies and interventions targeting FAW-affected areas should prioritize food diversity among children and mothers to avert the short and long-term effects of poor nutrition due to FAW infestation.

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1 Introduction

In recent years the Fall armyworm (FAW) has emerged as one of the major pests in Africa. This is due to the widespread negative effects it imposes on Africa's farming systems, especially for vulnerable smallholder farmers. The FAW arrived in West Africa in 2016, and spread rapidly throughout the continent, currently affecting 44 countries (Rwomushana et al., 2018). FAW is estimated to affect 37 million hectares of land in sub-Sahara Africa (SSA) (Hruska, 2019). Recent estimates indicate losses of 4.1-17.7 million tons of maize annually due to FAW (Rwomushana et al., 2018). In monetary terms, this colossal crop damage is estimated to cost between US$ 2.5 and 6.3 billion per annum, enough to feed 40 million to 100 million people (Day et al., 2017; FAO, 2020).

The large-scale damages attributed to FAW infestations impact Africa's agriculture and consequently food security. Firstly, FAW largely invades maize, the primary staple for 300 million people in Africa (Hailu et al., 2018). Maize accounts for 25 million hectares of SSA's farmland and 20% caloric intake for half of the region's population (Gianessi, 2014). Secondly, many Africans depend on agriculture for their livelihood, with 54% of the total population employed in the sector (ILO, 2017). Therefore, FAW infestations pose a significant threat to the food security and livelihoods of the majority of Africans.

Like the rest of the African continent, maize in Uganda is dominated by smallholder farmers and strategic to its food security. Approximately 70% of the maize is produced by smallholders, whose welfare depends on the performance of the maize sector (Shiferaw *et al*., 2011; Kalule *et al*., 2006). Nutritionally, maize provides 40 percent of Uganda's calorie requirements, with an average of 23 kgs per capita consumed annually (Kalule *et al*., 2006; Kagonda *et a*l., 2016). Hence, the rapid spread of FAW infestation in Uganda has dire consequences on the country's food security and economic performance.

The first FAW detection in Uganda was in 2016's first cropping season, where farmers had wrongly reported it as an influx of stemborer infestation (Otim et Al., 2018). Day et al. (2018) estimated maize production loss caused by FAW in Uganda to range from 558.9 -1391.1 thousand Mt and $163.7-407.5 million annually.

Previous studies on the impact of FAW in Africa predominantly focused on quantifying yield and production losses caused by FAW infestation. In this vein, a study based on survey data by (Abrahams et al., 2017 and Day et al., 2017) revealed that FAW had the potential to cause maize yield losses ranging from 8.3 to 20.6 million tonnes per annum or approximately 21–53% of production (Abrahams et al., 2017; Day et al., 2017). Further, Kumela et al. (2018) , who measured maize yield losses using farmers' own estimates in Kenya found average losses of up to 47%, while direct measurement of FAW losses in two districts in Zimbabwe estimated losses at 11.6% (Day et al., 2017). Furthermore, using farm-level estimates from Ghana and Zambia, the authors suggested yield losses of 22–67 percent (Day et al., 2017).

More recent studies have advanced the estimation techniques for yield losses by combining various data. De Groote et al. (2020) combined nationally representative community survey data with national production data from statistical agencies, FAO, and the World Bank to estimate production losses at the national and sub-national levels in Kenya. This study established that Kenya's maize yield losses due to FAW in 2018 were 33%, which varied across the country's different regions. In this study, the authors acknowledge the shortcomings in the available methods for estimating crop losses. Firstly, they note that pest incidences and the resulting losses can be highly variable, both over space and over time. Secondly, they observed the difficulty of establishing good control plots, where only the pest understudy is eliminated and not other pests, which can then be compared to the infested plot. The authors also note the scarcity of studies that undertake direct and systematic loss assessments due to this limitation (De Groote et al., 2020).

Given the foregoing, there is a paucity of studies that have generated empirical evidence on the causal effects of FAW on key outcomes. Previous research on the link between FAW and outcomes such as yield and FAW control strategies were largely based on mean comparisons using household survey data and on-farm experiments without accounting for other factors that can influence yield and FAW infestation (Kassie et al., 2020). To address the limitations, Kassie et al., (2020) conducted a rigorous economic analysis of the impacts of FAW in Ethiopia by comparing the yield of FAW-infested farmer plots with FAW-free plots (control plots). The authors also estimated the impact of FAW on other outcomes, including quantities of maize sales and per capita maize consumption. Their findings indicate that FAW exposure affects maize yield and sales negatively, but not consumption (Kassie et al., 2020).

Previous studies have been pioneering, and thus instrumental in shaping our understanding of the effects of FAW on productivity. However, knowledge gaps persist on the effects of FAW on nutrition security. In many FAW impact studies, whose primary focus is estimating yield and production losses, food security effects are only implied. As such, the impact of FAW on nutrition security remains under-studied.. There are several pathways through which FAW can affect nutrition security, which requiring further examination.

This study contributes to the body of knowledge by establishing the causal effects of FAW infestation on nutrition security. We determine the effects of FAW on Dietary Diversity Score (DDS) as a proxy for nutrition. Specifically, we: i) examine pathways through which FAW affects household nutrition security; ii) estimate the impact of FAW on maize yields, maize sales, and insecticide use; and iii) estimate the impact of FAW on dietary diversity for children and mothers.

Findings from this study will inform policymakers and those involved in food security programs for smallholders in Uganda and the rest of developing countries. This study also provides a framework for understanding the food security effects of FAW, which has spread to different parts of the developing world.

The rest of the article is organised as follows: we present the conceptual framework in section 2; the study area and data sources are discussed in section 3; in section 4 we present the main descriptive statistics; section 5 the econometric strategy; section 6, we present and discuss the results and the article concludes in section 7.

2. Conceptual Framework

We construct a conceptual framework to guide our understanding of the pathways for the impact of FAW on nutrition security. Dietary diversity, measured by DDS, is our proxy for food nutrition security rather than Household Dietary Diversity Score (HDDS) because our primary concern is to measure nutrient adequacy and make comaprisons among different sub-groups within our population. Individual DDS is commonly used in the nutrition literature, as an indicator of nutrient adequacy and access to a variety of foods. DDS has been found to be positively correlated with macronutrient and micronutrient adequacy of diets for adults (Ogle et al., 2001; Foote et al., 2004; Arimond et al., 2010). Therefore, we believe DDS is a valid indicator of food nutrition security status.

The pathways for the impact of FAW on nutrition security is depicted in figure 1. The major pathway is through maize yield losses, which directly reduce the food available for the household to consume since maize constitutes a major source of calories for poor households (Kassie et al, 2015). Confronted with these FAW-induced shocks, households prioritize starchy staple consumption, thus, they would be less likely to consume diverse foods. Indirectly, FAW negatively affects household's maize sales by reducing maize yields, which in turn reduces income available for households to purchase diverse foods.

Another indirect effect of FAW infestation on food security is through increased expenditure on pesticides and labour. This is related to smallholders' management strategies to mitigate FAW infestations, such as pesticide use and handpicking (Kassie et al., 2020). The latter increases household expenditure on pesticides while the former increases labour costs. Hence, FAW incidences are likely to increase households' operating costs, resulting in reduced income for purchasing diverse foods.

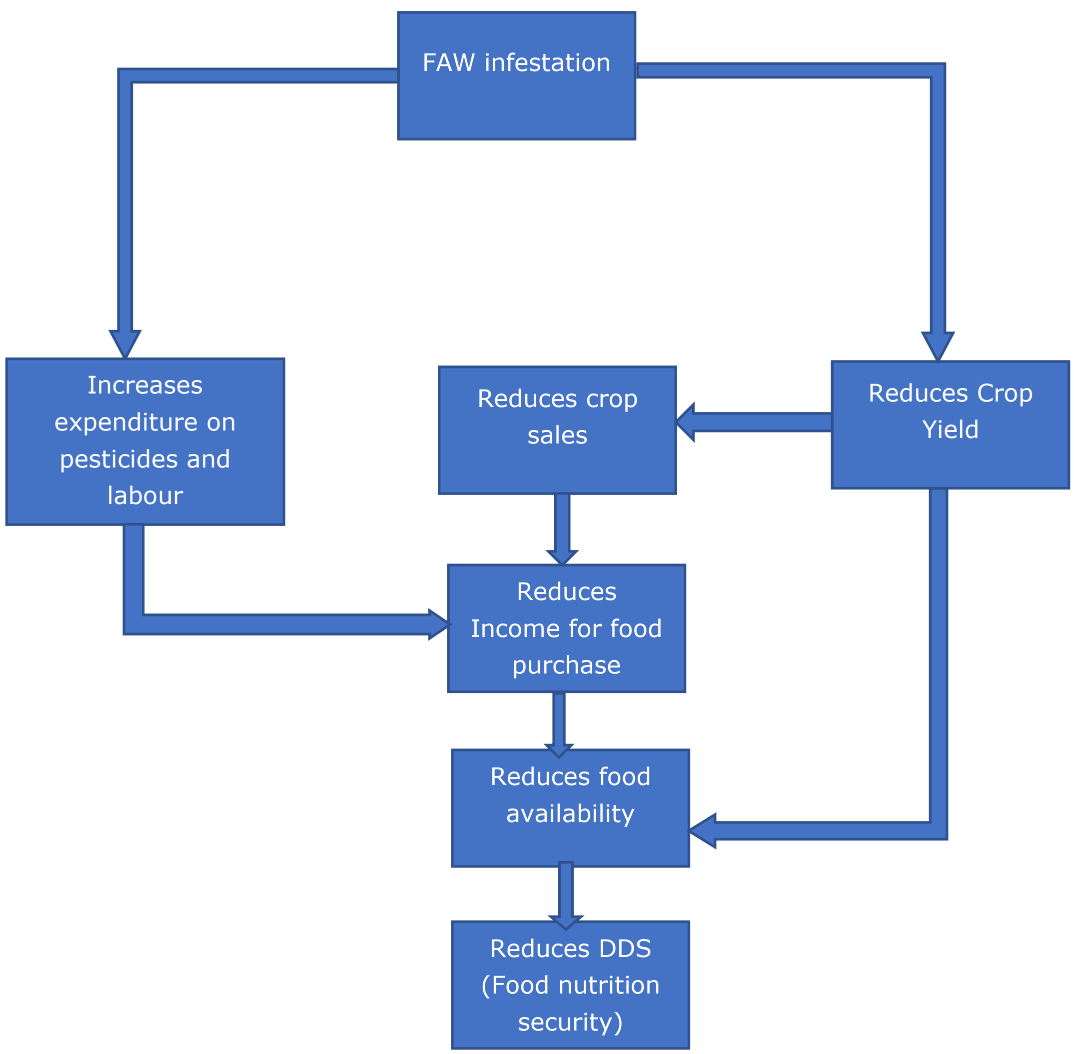

Figure 1: Pathways for the Impact of FAW on Food Nutrition Security
Source: Authors' own construction

3. Study Area and Data Sources

The main source of data for this study is a household survey conducted in Kamuli District in the Eastern region of Uganda (Figure 2).

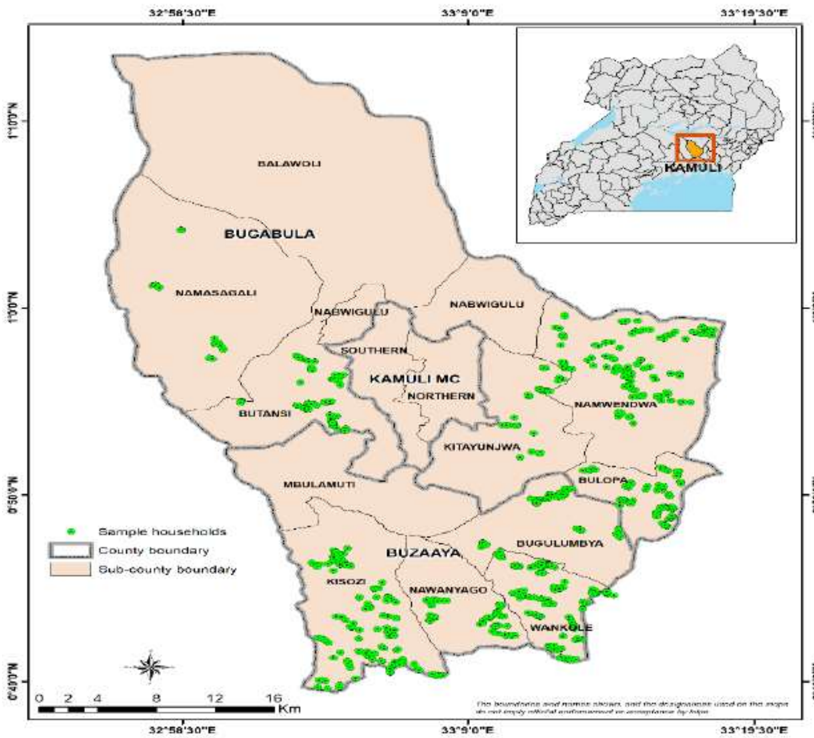

Figure 2: Sample distribution in Kamuli District
Source: Makerere University and *icipe*,

Icipe conducted the baseline survey in November 2019, which targeted maize farmers for the Combating Arthropod Pests for Better Health, Food and Resilience to Climate Change (CAP-Africa) Project . The data was collected for three seasons: the short rain season September/October 2018; the long rain season March/April 2019; and the short rain season August/September 2019. Kamuli District was purposively selected due to its high production of maize and high invasion of FAW, stemborer, and Striga. A multi-stage stratified random sampling framework was then applied to select 11 sub-counties out of the 13. Random proportionate to size sampling was then used to select villages from the chosen sub-counties and 920 maize farmers to include in the study.

4.0 Treatment and Outcome Variables

We present the treatment and outcome variables in this section. The treatment variable is the incidence of FAW on the plot as reported by the farmer (1=plot suffered from FAW, and

0=otherwise). In this regard, the unaffected plots are control plots. We asked farmers if they were also affected by other plot shocks including stemborer (1=plot suffered from stemborer, and 0=otherwise); striga (1=plot suffered from striga, and 0=otherwise); and other stresses such as diseases (1=plot suffered from striga, and 0=otherwise). Out of a total of 3,355 plots in the sample, 2,503 (73.9%) were affected by FAW. Stemborer, striga and other stresses affected 49.3%, 64.5% and 57.5% of the plots respectively. Table 2 indicates that higher proportions of FAW affected plots were affected by the other stresses and that these differences are statistically significant.

The first outcome variable is yield measured in Kg/Ha for each plot. The mean yield in the total sample is 1,477 Kg/Ha (table 1). The average yield for the FAW affected plots was 1,449 kg/Ha while that for the control plots was 1,606 Kg/Ha and the difference is statistically significant. The self-reported yield losses resulting to FAW in the sample is estimated at 36.5%.

Table 1: T-tests summary statistics for selected variables

Variables	Not Affected by FAW	Affected by FAW	P-value
Outcome Variables			
Maize yield (Kg/Ha)	1605	1449	0.0002***
Maize quantities sold (kg)	735	596	0.0000***
Value of maize sales (000 UGX)	491,240	386,918	0.0000***
Insecticide use (1/0)	0.163	0.245	0.0000***
Insecticide use (ltr/Ha)	1.693	1.967	0.0157**
Insecticide cost (UGX)	15,785	17,906	0.0761*
DDS Child 24 hours recall	6.795	6.360	0.0000***
DDS Child 7 days recall	9.211	9.212	0.9958
DDS Mother 24 hours recall	6.637	6.262	0.0000***
DDS Mother 7 days recall	9.100	8.969	0.0056***
Plot shocks			
Stemborer (1/0)	0.118	0.493	0.0000***
Striga (1/0)	0.295	0.648	0.0000***
Plot investments			
Urea use (kg/ha)	48.428	48.284	0.9665
DAP use (kg/ha)	47.130	45.900	0.6179
Seed use (kg/ha)	28.997	29.677	0.2493
Plot characteristics			
Good plot fertility	0.419	0.300	0.0000***
Irrigation (1/0)	0.003	0.001	0.0002***
Intercropped (1/0)	0.524	0.538	0.2222
Plot tenure (1 = owned, 0 otherwise)	0.762	0.774	0.200
Household characteristics			
Sex of household head (1 = male, 0 otherwise)	0.859	0.869	0.188
Age of the household head (years)	48.903	48.693	0.4643
Family size (number)	6.757	7.158	0.0000***
Education of household head (years)	9.627	9.097	0.0000***
Value of livestock owned '000 UGX	1019	1067	0.1828
Household income '000 UGX	1665	1817	0.0005***

5.0 Measurement of DDS

We compute DDS for children under the age of five years and their mothers, developed following the FAO (2010) guidelines. We define DDS as the number of unique food groups consumed in the previous 24 hours and 7 days period by children and mothers in a household. Our survey captured 22 food groups, which we aggregated to the recommended 12 groups based on FAO guidelines. The 12 food groups are cereals, white tubers and roots, vegetables, fruits, meat, eggs, fish and other seafood, legumes, nuts, and seeds, milk and milk products, oil and fats, sweets, Spices, condiments, and beverages.

We further disaggregate DDS for each of the two groups -children and mothers- into 12 hours and 7 days recall periods. Some authors have had a preference for the 12 hours recall as a short period, which is likely to increase the degree of self-reporting accuracy compared to longer recall periods (Mulenga et al., 2021). Coversely, others contend that a 7 days recall perios is a better measure of an individual's habitual diet in the study context. In rural areas of low income countries, access to and affordability of healthy foods are highly problematic, and food consumption can, therefore, differ enormously from one day to the next. While repeated 24-hour recall offers a way to overcome some of the limitations of 24-hour recall data for collecting accurate information on dietary habits, this is not possible in many studies due to budgetary implications (Kassie et al., 2020).

Gupta et al. (2020) used two recall periods (24-hour and 7-day) to study the effects of production diversity on dietary diversity scores and found consistent results regardless of which time period was used. Our approach is similar to Gupta et al. (2020), except that we measure individual dietary diversity (DDS) and not HDDS.

6.0 Econometric Estimation Strategy

We present our estimation strategy to determine the effects of FAW on our outcome variables of interest. We firstly apply an exogenous treatment framework, which assumes that FAW incidence is an exogenous shock to farmers (Kassie et al., 2020). Essentially, we assume that FAW infestation at a farmer's plot is independent of our outcome variables. Hence, we apply the following specification to each of our outcome, which we estimate using the Ordinary Least Squares (OLS) estimator similar to Kassie et al. (2020):

$$Y_{ip} = \beta F_{ip} + \omega X_{ip} + \varphi V_j + \gamma_{ip} \qquad (1)$$

Where i and p represent the household and plot respectively and Y_{ip} are the outcome variables including maize yield, maize sales, insecticide use, DDS for children under 5 years and DDS for mothers. In our model, maize yield and insecticide use are measured at the plot level, while maize sales and DDS are measured at indivdiual level. F_{ip} is a dummy variable for FAW exposure, equal to 1 if the plot was affected by FAW and 0 otherwise. X_{ip} is a vector of observable plot and household level covariates. The vector of X_{ip} in this model included plot investments, plot and household characteristics. We also control for shocks that affected the plot other than FAW, namely stemborer, Striga, and other shocks. In this way, the model accounts for the potential effects of other pests that may have infested plots simultaneously with FAW, noting that it would be a near-impossible task to designate pure control plots having some pests and not others (De Groote et al., 2020). The V_j captures fixed effects at sub-county level, which account for variations in the agro-ecological, market and economic conditions. Given the explanatory variables, we compare different specifications of equation (1) by varying the vector of X_{ip}, while V_j is included in some models and not in others. We compare all our model specifications based on values of the Akaike's information criterion (AIC) and Bayesian information criterion (BIC). Finally, γ_{ip} is the error terms specific to the household and plot while the parameters to be estimated by the models are β, ω and φ. We are primarily interested in the estimated size and sign of FAW impact, β, which can also be interpreted as the marginal change from the base level of the outcome variable.

The exogenous treatment framework in (1) does not allow us to exploit variation of plot and household variables across time. Taking advantage of the seasonal data at our disposal we take special interest in using our constructed panel data for estimating another model that accounts for individual effects. Our panel model takes the general form:

$$Y_{ipt} = \alpha_{ip} + \partial F'_{ipt} + \mu X'_{ipt} + \gamma_{ipt} \qquad (2)$$

Where the subscripts i represents the household, p is the plot and t is time, which in this case represents season 1 and 2 (the short rain season of 2018 and long rain season of 2019). α_{ip} represents unobserved time-invariant covariates or individual-specific effects (Cameron and Trivedi, 2010). F' is the dummy variable for FAW infestation at plot, X' is a vector of observed time-varying and time-invariant covariates and γ_{ipt} is the random disturbance term. Y_{it} are the outcome variables, ∂ and μ are the parameters to be estimated. We make a reasonable assumption that the unobserved time-invariant plot or household characteristics can be correlated with covariates X'. Therefore, we estimate a Fixed Effects rather than a Random Effects model.

Given the limitation with our data, we could only estimate panel models for two of our outcome variables, maize yield and insecticide use as the other outcome variables did not vary between the two seasons.

As a robustness check, we formally test the exogeneity assumption that we used to estimate equation (1) with OLS because one might be concerned that the intensity of FAW might be correlated with unobservable factors that are also correlated with outcome variables. Among the underlying assumptions of OLS is that the model error term is unrelated to the regressors i.e. $E(u|x) = 0$. If this assumption is violated, we can no longer make any causal inference interpretation. Essentially we test for endogeneity of our treatment variable (F_{ip}) from the first stage regression, also referred to as the reduced form regression. If we find a valid instrumental variable Z_i, correlated with F_{ip} but not with Y_{ip} , it will be used as an instrument for our treatment variable F_{ip} as in equation (2).

$$Y_{ip} = \beta Z_i + \omega X_{ip} + \varphi V_j + \gamma_{ip} \qquad (3)$$

For all the models described above we made the transformation of a number of variables. We transformed maize yield into natural logarithm scale, which enabled us to interpret the treatment coefficients as a percentage change. We transformed insecticide use, maize sales quantities, hired labour, urea, and DAP using inverse hyperbolic sine (IHS) transformation, as some farmers have zero values for these variables.

7.0. Results and Discussion

7.1 Descriptive statistics

This section is a description of the key variables used in the study. It is worth noting that the data represents three rain seasons for Uganda, hence, the subsequent analysis averaged all the reported statistics for the 3 seasons. Also note that at the time of data collection, production and sales data were not yet available for the short rain season Aug/Sept 2019, hence these variables were unavailable for our analysis.

From a total sample of 920 households, there was a total of 1,047 farm plots from the short rain season of 2018; 1,124 plots from the long rain season March/April 2019 and 1,184 plots from the short rain season of 2019. The sample households grew maize on 1.28 plots on average and 24.8% of the surveyed households grew maize on more than one plot.

7.2 Plot and Household Sample Characteristics

Plot and household sample characteristics are summarised in table 1. Among the plot investment characteristics including urea use, DAP use, seed use, cost of hired labour, frequency of weeding and herbicide use. Average urea use per hectare was 48 kg/Ha, while DAP was 46 Kg/Ha and average seed application rate was 29 kg/Ha. Weeding on a plot was done nearly 3 times on average and herbicide application is low at 6% of the plots. Plot characteristics include plot fertility (good, medium and poor), plot slope (gentle, medium and steep), slope depth (shallow, medium and deep), manure application, irrigation, intercropping, plot distance to residence and plot tenure.

Table 2: Variables and summary statistics

Variables	Mean	Standard Deviation
Outcome Variables		
Maize yield (Kg/Ha)	1,477	1279
Maize quantities sold (kg)	644	1177
Value of maize sales (000 UGX)	421	871
Insecticide use (1/0)	0.224	0.417
Insecticide use (ltr/Ha)	1.916	2.164
Insecticide cost (UGX)	17503	22832
HDDS Child 24 hours recall	6.324	1.800
HDDS Child 7 days recall	9.107	2.106
HDDS Mother 24 hours recall	6.245	1.707
HDDS Mother 7 days recall	8.909	1.897
Plot shocks		
Fall armyworms (1/0)	0.739	0.439
Stemborer (1/0)	0.395	0.489
Striga (1/0)	0.556	0.497
Other shocks (1/0)	0.5120	
Plot investments		
Urea use (kg/ha)	48.318	53.562

Variables	Mean	Standard Deviation
DAP use (kg/ha)	46.209	45.722
Seed use (kg/ha)	28.980	19.308
Total cost of hired labour in UGX	74,588	178,999
Frequency of weeding	2.807	3.139
Herbicide use (1/0)	0.062	0.242
Plot characteristics		
Good plot fertility	0.330	0.470
Medium plot fertility (1/0)	0.522	0.500
Poor plot fertility (1/0)	0.148	0.355
Gentle slope plot	0.520	0.500
Medium slope plot (1/0)	0.457	0.498
Steep slope plot (1/0)	0.022	0.148
Shallow depth plot	0.149	0.356
Medium depth plot (1/0)	0.431	0.495
Deep depth plot (1/0)	0.420	0.494
Manure (1/0)	0.029	0.169
Irrigation (1/0)	0.011	0.105
Intercropped (1/0)	0.534	0.499
Plot distance to residence (walking minutes)	24.780	171.219
Plot tenure (1 = owned, 0 otherwise)	0.770	0.421
Household characteristics		
Sex of household head (1 = male, 0 otherwise)	0.861	0.346
Age of the household head head (years)	48.828	13.346
Family size (number)	6.924	2.619
Education of household head (years)	9.319	4.712
Value of livestock owned ‘000 UGX	1029	1676
Household income ‘000 UGX	1778	1979

On average, 52% of the plots were of medium fertility, 52% of the plots were on a gentle slope and 43% were on a medium depth plot. Manure application on plots was low, practiced on 3% of plots, and irrigation constituted a paltry 1% of plots. 53% of plots were intercropped and the average plot distance to residence was 24 walking minutes. On average 77% of the plots were owned by the households.

Household characteristics included sex of the household head, age of the head, family size, education of the head, value of livestock owned and total household income. 86% of households were male-headed with an average age of household head at nearly 49 years and mean number of years of schooling for the head was 9.3. The value of household owned was UGX 1.02 Million and total annual income was UGX 1.78 Million.

Figure 3 illustrates maize yield differences between the affected and unaffected plots using non-parametric (kernel) estimates. The figure indicates a negative correlation between FAW infestation and yield.

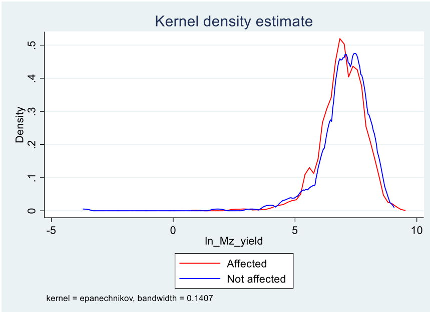

Figure 3: Non-parametric estimation of maize yield (kg/ha)

Similarly, the kernel estimates plot for quantity of maize sales indicates an inverse relationship between FAW and maize sales (figure 4), while a postive relationship between FAW infestation and insecticide use-rate depicted by the kernel plot (figure 5).

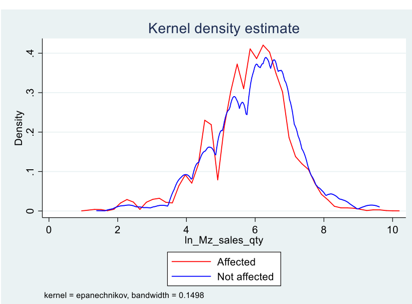

Figure 4: Non-parametric estimation of maize quantities sold (kg)

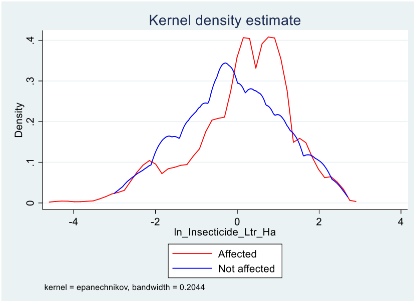

Figure 5: Non-parametric estimation of insecticide use (liters/Ha)

7.3 Econometric results

This section presents and discusses the Impact of FAW on our outcome variables. Table 3 summarizes the impact of FAW on maize yield, maize sales and insecticide use. The results indicate a negative and statistically significant impact of FAW on maize yields. On the basis of pooled OLS model, FAW infestation on average caused yield losses of 40% after controlling for covariates that influence yield. This figure is close to the self-reported yield loss by respondents, which was 36.5%. However, we did not find a statistically significant causal effects of FAW on yield on the basis of the fixed effects model. This is likely because fixed effects coefficient estimates are not precise when there is little variation within (Cameron and Trivedi, 2010). As is the case with our data, there is limited variation within i.e between the two short and long rainy seasons. Notwithstanding, results from the pooled OLS model agree with with our earlier postulation of a negative effect of FAW on maize yields and this is similar to previous findings by (De Groote et al., 2020; Kassie et al., 2020).

Further, our findings suggest there is causal link between FAW infestation and maize sales. In line with our earlier postulation, FAW infestation on average reduced quantities of maize sold by farmers by 48 % (table 3). The findings are similar to Kassie et al (2020), who found a negative and statistically significant impact of FAW on maize sales. Finding a large effect of FAW on maize sales suggests households may have held on to their available maize crop in preference for consumption, hence the the large negative effect size of FAW on maize sales.

Estimates from the pooled OLS indicate that FAW infestation had a positive and statistically significant effect on the use of insecticide (table 3). This suggests that FAW increased the intensity of insecticide use by farmers to rise by almost 19%. In agreement with our conceptualization, FAW infestation resulted in increased insecticide usage and likely also increased household expenditure on insecticides . This potentially diverts income away from spending on foods with the likely impact of reducing DDS (Tambo et al., 2020). Further, previous studies have pointed out the negative health implications of increased use of insecticides (Kassie et al., 2020). The fixed effects model with respect to FAW impact on insecticide use was not statistically significant for similar reasons given for maize yield.

Table 3: Impact of FAW on maize yield, maize sales and insecticide use

	Maize yield (kg/Ha)		Maize sales (Kg)	Insecticide use (liters/Ha)	
Variables	Pooled OLS (1)	Fixed Effects (2)	Pooled OLS (3)	Pooled OLS (4)	Fixed Effects (5)
FAW Affected	-0.397***	-0.127	-0.484***	0.192**	-0.00837
	(0.0756)	(0.102)	(0.0822)	(0.0745)	(0.177)
Household characteristics	Yes	No	Yes	Yes	No
plot shocks	Yes	Yes	Yes	Yes	Yes
Plot investments	Yes	Yes	Yes	Yes	Yes
Plot characteristics	Yes	No	Yes	Yes	No
Sub-county fixed effects	Yes	No	Yes	Yes	No
Constant	6.092***	7.088***	7.814***	-0.683*	0.633**
	(0.389)	(0.164)	(0.272)	(0.381)	(0.270)
Observations	738	1,445	936	678	398
R-squared	0.322	0.074	0.351	0.384	0.163

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We earlier postulated pathways through which FAW infestation potentially affects nutrition security, herein measured by DDS. Finding a negative impact of FAW on maize yields, maize sales and a postive impact on insecticide use rate affirms our postulation. Our postulation suggests that these effects are expected to generate negative impacts on nurtition security. Table 4 summarises the impact of FAW on DDS for children under 5 years using the 24 hours and 7 days recall periods. As expected, FAW has a negative and statistically significant impact on children's DDS for both the 24 hours and 7 days recall periods. FAW infestation caused children's DDS to fall by 1.10 and 0.65 points based on the 24 hours and 7 days recall period respectively. Given the sample DDS averages of 6.32 and 9.12 based on the 24 hours and 7 days recall periods respectively, this implies that FAW caused DDS to fall by 17% and 9% respectively. The differences in the DDS estimates when using the 24 hours and 7 days recall periods may be due to measurement aspects related to the two recall periods already referred to. Especially for children under 5 years, high variability in food access from one day to the next may account for the observed differences in DDS as well as the estimated size of the FAW impact.

Table 4: Impact of FAW on DDS for children under 5 years using the 24 hours and 7 days recall periods

VARIABLES	DDS children under 5 years (24 hours recall) OLS Pooled (1)	DDS children under 5 years (7 days recall) OLS Pooled (2)
FAW Affected	-1.099***	-0.649***
	(0.263)	(0.207)
Household characteristics	Yes	Yes
plot shocks	Yes	Yes
Plot investments	Yes	Yes
Plot characteristics	Yes	Yes
Sub-county fixed effects	Yes	Yes
Constant	8.460***	11.55***
	(0.885)	(0.887)
Observations	399	399
R-squared	0.507	0.673

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The impact of FAW infestation on DDS for mothers using the 24 hours recall period is sumamrised in table 5. As expected FAW infestation has a negative and statistically significant impact on DDS for mothers and this is consistent regardless of whether the 24 hours or 7 days recall period is used. FAW infestation caused mother's DDS to fall by 0.86 and 0.87 points based on the 24 hours and 7 days recall period respectively. Notably, the size of the impact of FAW on mothers is very similar for the 24 hours and 7 days recall periods. This may imply less variability in mothers' consumption on a day to day basis compared to children. Given the DDS averages of 6.25 and 8.91 as measured by the 24 hours and 7 days periods respectively, this means that mothers' DDS were 14% and 10% lower as a result of FAW infestation respectively.

Table 5:Impact of FAW on DDS for women using the 24 hours and 7 days recall periods

Variables	DDS mothers (24 hours recall) Pooled OLS (1)	DDS mothers (7 days recall) Pooled OLS (2)
FAW Affected	-0.855***	-0.871***
	(0.156)	(0.139)
Household characteristics	Yes	Yes
plot shocks	Yes	Yes
Plot investments	Yes	Yes
Plot characteristics	Yes	Yes
Sub-county fixed effects	Yes	Yes
Constant	12.23***	11.79***
	(0.600)	(0.611)
Observations	804	810

R-squared	0.335	0.510

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Combining the analyses for children and mothers allows us to crystallise FAW's mpact on nutrition security. Firstly we note that FAW had a negative and statistically signifcant impact on DDS for both mothers and children regardless of whether we use the 24 hours or 7 days recall periods. However, the magnitude of the impact of FAW is more pronounced for children than mothers, which suggests that children are more vulnerable to the effects of FAW. The higher vulnerability may be related to variablity in access to food specifically for children. More stability is observed in the DDS for mothers, which are similar for the 24 hours and 7 days recall periods. This further accentuates children's vulnerability to the deletrious effects of FAW infestation on their nutrition security.

We checked the robustness of our findings by putting our exogeneity assumption to a test. Essentially, we tested a number of potential intrumental variables for FAW infestation. If a valid and strong instrumental variable were to be found, this would mean that model specification (3) in section 6.0 is the correct model and not specification (1). Our search for instrumental variables was met with the pervasive challenge of not finding any valid instrument. This led us to the conclusion that model specification (1) could be used for the analysis. Some of potential instrumental variables we tested, among others, were: plot slope, altitude, intercropping, plot distance to household, rotation of maize with a cash crop i.e coffee or sugarcane.

8.0 Conclusions

In this paper we estimated the impact of FAW infestations on the nutrition security of children and mothers in Eastern Uganda. Using plot and household level data collected from 920 households from Kamuli District, we estimated the impact of FAW infestation on DDS of children and mothers. DDS was our main indicator of food nutrition security status. To the best of our knowledge, this is the first study in Uganda that established a causal relationship between FAW infestations and the nutrition security of women and children.

Similar to previous studied we find a statistically significant and negative impact of FAW infestations on maize yields. FAW infestation caused a 40% decline in maize yields. FAW exposure had an even larger effect on maize sales leading to a reduction of 48%. Furthermore insecticide use by farmers increased by 19% due to FAW infestation. Taken together these findings lend credence to our postulation of the pathways through which FAW infestations ultimately affects children and mothers' nutrition security.

We find a negative and statistically significant impact of FAW infestation on the nutrition security of mothers and children regardless of whether the 24 hours or 7 days recall period was used. FAW infestation caused the DDS for children under 5 years to fall by 1.10 and 0.65 points using the 24 hours and 7 days recall periods respectively. The discrepancy between the two recall periods may be a reflection of high variability in food access for children. This increases the vulnerability of children to the effects of FAW infestation and many other exogenous shocks that may affection nutrition security.We also find a negative and statistically significant impact of FAW infestation on DDS for mothers. Using the 24 hours and 7 days recall periods, we find that FAW infestation caused DDS to reduce by 0.86 and 0.87 points respectively. In contrast to children, the impact of FAW on DDS is more consistent for the two recall periods used. Also worth mention is our finding that FAW had a larger impact on the DDS for children than mothers. The larger effect on children implies that the already precarious nutrition security especially for children under the age of 5 years is exacerbated by the occurrence of FAW infestations.

Our check for the robustness of our estimates confirmed that our exogeneity assumption for the treatment variable is valid. This is because we could not find a valid and strong instrumental variable that would have invalidated our initial assumption. Further research in this regard is required in different settings to further explore if this assumption holds. This should include deliberate collection of data on variables that can used as instrumental variables

The main limitation of this study is that panel data is not complete for all outcome variables. This limited our ability to fully explore panal data specifications for all outcome variables. As we alluded to before, there is limited variation within, that is, the short and long rainy seasons hence the fixed effects model specification estimations were imprecise. A fixed effects model specification on all our outcome variables would partially address some of the potential endogeneity related to unobserved time-invariant covariates.

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Appendices

Appendix 1: Tables with full regression results for all outcome indicators

Appendix 1A: Maize yield estimation, kg/ha

VARIABLES	(1) Household Characteristics	(2) Household characteristics and plot shocks	(3) Household characteristics plot shocks and plot investments	(4) Household characteristics plot shocks plot investments & plot characteristics
1.Affected	-0.0731**	-0.0405	-0.483***	-0.397***
	(0.0341)	(0.0349)	(0.0743)	(0.0756)
1.maleheaded	0.170***	0.165***	0.520***	0.580***
	(0.0366)	(0.0363)	(0.170)	(0.184)
c.age#c.age	-7.30e-06	-9.81e-06	5.38e-05***	2.71e-05
	(8.59e-06)	(8.62e-06)	(1.99e-05)	(2.04e-05)
hh_size	0.0193***	0.0209***	0.0148	0.0238**
	(0.00472)	(0.00468)	(0.0132)	(0.0119)
education	-0.00349	-0.00411*	0.00943	0.00415
	(0.00246)	(0.00245)	(0.00872)	(0.00820)
hh_income_000	1.76e-05***	1.62e-05***	1.13e-05	-1.14e-07
	(5.40e-06)	(5.44e-06)	(1.34e-05)	(1.39e-05)
1.stemborer		0.0163	0.0667	0.0948
		(0.0272)	(0.0644)	(0.0691)
1.striga		-0.0844***	0.0959	0.0669
		(0.0314)	(0.0884)	(0.0889)
1.other_stress		-0.121***	0.00165	-0.0290
		(0.0272)	(0.0774)	(0.0770)
ihs_Urea_Kg_Ha			0.121**	0.0769
			(0.0504)	(0.0530)
ihs_DAP_kg_Ha			0.144***	0.119**
			(0.0552)	(0.0597)
seed_kg_Ha			0.0122***	0.0125***
			(0.00244)	(0.00220)
hired_labour_Ha				2.05e-07*
				(1.13e-07)
Times_plot_weeded			0.0295	-0.0118
			(0.0224)	(0.0182)
1.herbicides_use			0.0211	-0.0337
			(0.0845)	(0.0860)
1.Good_Plot_fertility				0.0884
				(0.114)

1.Medium_Plot_fertility				0.0854
				(0.111)
1o.Poor_Plot_fertility				-
1.Gentle_slope				-0.554***
				(0.157)
1.Medium_slope				-0.449***
				(0.152)
1o.Steep_slope				-
1.shallow_depth_plot				-0.351***
				(0.110)
1.medium_depth_plot				0.276***
				(0.0859)
1o.deep_depth_plot				-
1.manure_use				0.00871
				(0.230)
1.irrigated				0.0224
				(0.123)
1.intercropping				-0.248***
				(0.0749)
Distance				0.000271
				(0.000628)
1.Tenure				0.0304
				(0.0712)
2.sub_county	0.287***	0.234***	0.213*	0.294**
	(0.0455)	(0.0479)	(0.118)	(0.118)
3.sub_county	-0.0709*	-0.0705*	0.0263	0.338**
	(0.0406)	(0.0404)	(0.133)	(0.136)
4.sub_county	0.208***	0.184***	0.0953	0.0878
	(0.0464)	(0.0468)	(0.135)	(0.133)
5.sub_county	0.184***	0.0974*	-0.382**	-0.265*
	(0.0457)	(0.0514)	(0.192)	(0.158)
6.sub_county	0.207***	0.226***	-0.0258	0.0980
	(0.0509)	(0.0506)	(0.116)	(0.125)
7.sub_county	0.115**	0.0903*	-0.179	-0.0893
	(0.0514)	(0.0518)	(0.122)	(0.120)
9.sub_county	0.368***	0.356***	0.221**	0.333***
	(0.0405)	(0.0416)	(0.0874)	(0.0991)
12.sub_county	0.379***	0.317***	0.410***	0.523***
	(0.0437)	(0.0474)	(0.121)	(0.122)
13.sub_county	0.266***	0.233***	0.238	0.224
	(0.0438)	(0.0457)	(0.175)	(0.223)
ihs_hired_labour_Ha			0.00301	
			(0.00595)	
11.sub_county	-2.143*	-2.195**		
	(1.097)	(1.106)		
Constant	6.602***	6.735***	5.428***	6.092***
	(0.0710)	(0.0775)	(0.351)	(0.389)
Observations	6,141	6,141	738	738
R-squared	0.047	0.052	0.245	0.322
AIC	16490.4	16468.2	1796.7	1738.7
BIC	16604.7	16602.6	1911.8	1904.4

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix 1B: Maize sales quantities estimation, kg

	(1)	(2)	(3)	(4)
VARIABLES	Household Charactristics	Household characteristics and plot shocks	Household characteristics plot shocks and plot investments	Household characteristics plot shocks plot investments & plot characteristics
1.Affected	-0.126***	-0.120***	-0.537***	-0.484***
	(0.0314)	(0.0341)	(0.0860)	(0.0822)
1.maleheaded	-0.0710*	-0.0712*	0.108	0.0957
	(0.0376)	(0.0377)	(0.0837)	(0.0795)
c.age#c.age	2.35e-05*	2.36e-05*	4.23e-05*	2.40e-05
	(1.22e-05)	(1.22e-05)	(2.31e-05)	(2.10e-05)
hh_size	0.0319***	0.0324***	0.0173	0.0169
	(0.00550)	(0.00551)	(0.0138)	(0.0135)
education	0.0234***	0.0231***	0.0260***	0.0222**
	(0.00314)	(0.00314)	(0.00923)	(0.0101)
hh_income_000	0.000112***	0.000113***	-6.08e-07	5.11e-06
	(5.63e-06)	(5.68e-06)	(1.17e-05)	(1.19e-05)
1.stemborer		-0.00132	0.158**	0.104
		(0.0305)	(0.0666)	(0.0664)
1.striga		0.0257	0.150**	0.140**
		(0.0333)	(0.0718)	(0.0670)
1.other_stress		-0.0654**	0.0106	0.0934
		(0.0293)	(0.0671)	(0.0649)
ihs_Urea_Kg_Ha			-0.0502	-0.0911**
			(0.0383)	(0.0403)
ihs_DAP_kg_Ha			0.139***	0.135***
			(0.0462)	(0.0453)
seed_kg_Ha			-0.00686***	-0.00562***
			(0.00193)	(0.00180)
hired_labour_Ha				5.11e-07***
				(1.26e-07)
Times_plot_weeded			0.0158**	0.0131
			(0.00780)	(0.00838)
1.herbicides_use			0.526***	0.503***
			(0.0979)	(0.100)
1.Good_Plot_fertility				0.273***
				(0.101)
1.Medium_Plot_fertility				0.360***
				(0.0959)
1o.Poor_Plot_fertility				-
1.Gentle_slope				-0.910***
				(0.122)
1.Medium_slope				-1.129***
				(0.123)

1o.Steep_slope				-
1.shallow_depth_plot				0.445***
				(0.0957)
1.medium_depth_plot				0.251***
				(0.0714)
1o.deep_depth_plot				-
1.manure_use				0.290*
				(0.150)
1.irrigated				-0.425
				(0.287)
1.intercropping				-0.362***
				(0.0680)
Distance				0.00322***
				(0.000733)
1.Tenure				0.0624
				(0.0738)
2.sub_county	0.372***	0.378***	0.133	0.132
	(0.0464)	(0.0498)	(0.114)	(0.117)
3.sub_county	-0.847***	-0.848***	-0.324**	-0.710***
	(0.0651)	(0.0652)	(0.138)	(0.168)
4.sub_county	-0.783***	-0.786***	-0.636**	-0.850***
	(0.0781)	(0.0785)	(0.253)	(0.256)
5.sub_county	-0.0615	-0.0567	-0.368**	-0.503***
	(0.0468)	(0.0512)	(0.166)	(0.180)
6.sub_county	-0.161**	-0.148**	-0.465***	-0.749***
	(0.0676)	(0.0675)	(0.147)	(0.157)
7.sub_county	0.192***	0.182***	-0.00205	-0.188
	(0.0418)	(0.0423)	(0.111)	(0.124)
9.sub_county	0.0637	0.0787	0.202*	0.0534
	(0.0524)	(0.0536)	(0.110)	(0.110)
12.sub_county	0.221***	0.225***	0.594***	0.516***
	(0.0690)	(0.0720)	(0.136)	(0.134)
13.sub_county	0.394***	0.407***	0.327	0.243
	(0.0523)	(0.0533)	(0.214)	(0.243)
ihs_hired_labour_Ha			0.0250***	
			(0.00633)	
Constant	6.445***	6.457***	6.861***	7.814***
	(0.0725)	(0.0754)	(0.255)	(0.272)
Observations	7,398	7,398	936	936
R-squared	0.135	0.135	0.274	0.351
AIC	23252.4	23252.7	2375.1	2291.3
BIC	23363.0	23384.0	2496.1	2465.6

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix 1C: Insecticide use estimation, liters/Ha

VARIABLES	(1) Household Charactristics	(2) Household characteristics and plot shocks	(3) Household characteristics plot shocks and plot investments	(4) Household characteristics plot shocks plot investments & plot characteristics
1.Affected	0.205***	0.179***	0.173**	0.192**
	(0.0404)	(0.0429)	(0.0745)	(0.0745)
1.maleheaded	-0.0774	-0.0767	-0.000911	-0.0321
	(0.0587)	(0.0585)	(0.0873)	(0.0866)
c.age#c.age	1.00e-05	1.07e-05	5.08e-06	7.50e-06
	(1.29e-05)	(1.29e-05)	(1.82e-05)	(2.07e-05)
hh_size	-0.0160**	-0.0159**	-0.0438***	-0.0466***
	(0.00622)	(0.00620)	(0.0117)	(0.0123)
education	-0.00782**	-0.00788**	-0.00801	-0.00705
	(0.00352)	(0.00351)	(0.00738)	(0.00751)
hh_income_000	-4.83e-05***	-5.04e-05***	-1.66e-06	-2.05e-05
	(7.77e-06)	(8.01e-06)	(1.63e-05)	(1.74e-05)
1.stemborer		0.0897***	-0.0435	0.0157
		(0.0330)	(0.0653)	(0.0684)
1.striga		-0.0189	-0.0356	0.000557
		(0.0361)	(0.0744)	(0.0744)
1.other_stress		-0.00438	-0.0666	-0.145**
		(0.0322)	(0.0581)	(0.0622)
ihs_Urea_Kg_Ha			0.0336	0.0352
			(0.0400)	(0.0405)
ihs_DAP_kg_Ha			0.301***	0.281***
			(0.0482)	(0.0467)
seed_kg_Ha			0.00912***	0.00871***
			(0.00198)	(0.00177)
hired_labour_Ha				2.94e-08
				(1.75e-07)
Times_plot_weeded			0.0319	0.0263
			(0.0194)	(0.0182)
1.herbicides_use			-0.156**	-0.130
			(0.0707)	(0.0815)
1.Good_Plot_fertility				0.163*
				(0.0952)
1.Medium_Plot_fertility				0.0747
				(0.0942)
1o.Poor_Plot_fertility				-
1.Gentle_slope				0.0657
				(0.271)
1.Medium_slope				0.0352
				(0.268)

1o.Steep_slope				-
1.shallow_depth_plot				-0.363***
				(0.0803)
1.medium_depth_plot				0.0104
				(0.0798)
1o.deep_depth_plot				-
1.manure_use				-0.335***
				(0.121)
1.irrigated				-0.405***
				(0.102)
1.intercropping				-0.0693
				(0.0663)
Distance				0.000479
				(0.000544)
1.Tenure				-0.0236
				(0.0669)
2.sub_county	0.131**	0.125**	0.193	0.223*
	(0.0528)	(0.0535)	(0.128)	(0.131)
3.sub_county	-0.0811	-0.0760	0.0832	0.371***
	(0.0527)	(0.0527)	(0.113)	(0.117)
4.sub_county	0.403***	0.397***	0.618***	0.768***
	(0.0740)	(0.0745)	(0.171)	(0.175)
5.sub_county	0.600***	0.581***	1.101***	1.236***
	(0.0647)	(0.0693)	(0.176)	(0.169)
6.sub_county	0.362***	0.357***	0.814***	0.894***
	(0.0699)	(0.0699)	(0.138)	(0.141)
7.sub_county	0.156***	0.161***	0.544***	0.635***
	(0.0518)	(0.0517)	(0.113)	(0.116)
9.sub_county	0.0741	0.0673	0.431***	0.472***
	(0.0572)	(0.0565)	(0.127)	(0.120)
12.sub_county	0.389***	0.381***	0.825***	0.836***
	(0.0643)	(0.0638)	(0.117)	(0.118)
13.sub_county	-0.0284	-0.0371	0.0827	0.101
	(0.0792)	(0.0808)	(0.204)	(0.229)
ihs_hired_labour_Ha			0.000560	
			(0.00514)	
Constant	1.114***	1.116***	-0.720***	-0.683*
	(0.0977)	(0.0991)	(0.264)	(0.381)
Observations	2,340	2,340	678	678
R-squared	0.104	0.107	0.346	0.384
AIC	5143.5	5142.1	1427.3	1409.6
BIC	5235.6	5251.5	1540.3	1572.3

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix 1D: HDDS children under 5 years (24 hours recall) estimation, score

VARIABLES	(1) Household Charactristics	(2) Household characteristics and plot shocks	(3) Household characteristics plot shocks and plot investments	(4) Household characteristics plot shocks plot investments & plot characteristics
1.Affected	-0.363***	-0.131*	-0.761***	-1.099***
	(0.0680)	(0.0710)	(0.247)	(0.263)
1.maleheaded	0.242***	0.303***	0.207	0.0875
	(0.0856)	(0.0872)	(0.449)	(0.392)
c.age#c.age	-2.40e-05	-4.09e-05*	0.000225***	0.000276***
	(2.37e-05)	(2.34e-05)	(7.18e-05)	(7.05e-05)
hh_size	0.0180	0.0157	0.0311	0.0149
	(0.0112)	(0.0110)	(0.0367)	(0.0387)
education	0.000577	0.000277	0.00466	0.0165
	(0.00582)	(0.00571)	(0.0273)	(0.0243)
hh_income_000	0.000205***	0.000214***	0.000317***	0.000399***
	(1.29e-05)	(1.32e-05)	(6.84e-05)	(6.58e-05)
1.stemborer		-0.412***	-0.450**	-0.0605
		(0.0545)	(0.208)	(0.244)
1.striga		-0.502***	-0.776***	-0.482*
		(0.0609)	(0.264)	(0.247)
1.other_stress		0.325***	0.820***	0.640***
		(0.0540)	(0.182)	(0.185)
ihs_Urea_Kg_Ha			0.138	0.338**
			(0.158)	(0.164)
ihs_DAP_kg_Ha			-0.180	-0.336*
			(0.168)	(0.182)
seed_kg_Ha			0.00367	0.00109
			(0.00870)	(0.00828)
hired_labour_Ha				-3.92e-07
				(4.91e-07)
Times_plot_weeded			-0.143**	-0.198***
			(0.0616)	(0.0674)
1.herbicides_use			0.517*	0.376
			(0.273)	(0.295)
1.Good_Plot_fertility				-1.187***
				(0.335)
1.Medium_Plot_fertility				-0.492
				(0.312)
1o.Poor_Plot_fertility				-
1.Gentle_slope				-0.289
				(0.518)
1.Medium_slope				-0.826
				(0.542)
1o.Steep_slope				-
1.shallow_depth_plot				-0.376
				(0.296)
1.medium_depth_plot				-0.241

				(0.319)
1o.deep_depth_plot				-
1.manure_use				-1.031
				(0.628)
0o.irrigated				-
1.intercropping				-0.682***
				(0.190)
Distance				-0.00747*
				(0.00409)
1.Tenure				-0.456**
				(0.190)
2.sub_county	0.188*	0.0299	0.286	0.842*
	(0.101)	(0.103)	(0.433)	(0.449)
3.sub_county	-0.218**	-0.228***	-0.156	-0.264
	(0.0867)	(0.0843)	(0.377)	(0.478)
4.sub_county	-0.359***	-0.384***	1.246**	1.611***
	(0.113)	(0.111)	(0.508)	(0.578)
5.sub_county	-0.470***	-0.783***	-0.841	-0.218
	(0.103)	(0.109)	(0.702)	(0.731)
6.sub_county	0.151	0.0655	-0.153	0.192
	(0.0956)	(0.0950)	(0.401)	(0.465)
7.sub_county	-0.576***	-0.491***	-0.491	-0.762
	(0.127)	(0.127)	(0.552)	(0.579)
9.sub_county	-0.0336	-0.260***	1.325**	1.717***
	(0.0884)	(0.0890)	(0.626)	(0.608)
12.sub_county	0.504***	0.220*	0.408	0.497
	(0.109)	(0.114)	(0.720)	(0.692)
13.sub_county	0.180*	-0.0122	0.0964	0.445
	(0.104)	(0.108)	(0.618)	(0.622)
ihs_hired_labour_Ha			0.0330**	
			(0.0140)	
Constant	6.125***	6.335***	6.430***	8.460***
	(0.165)	(0.171)	(0.894)	(0.885)
Observations	4,761	4,761	399	399
R-squared	0.100	0.126	0.430	0.507
AIC	18523.1	18387.0	1515.7	1475.7
BIC	18626.6	18509.9	1615.4	1611.3

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix 1E: HDDS children under 5 years (7 Days recall) estimation, score

VARIABLES	(1) Household Charactristics	(2) Household characteristics and plot shocks	(3) Household characteristics plot shocks and plot investments	(4) Household characteristics plot shocks plot investments & plot characteristics
1.Affected	-0.0961	-0.0697	-0.504**	-0.649***
	(0.0703)	(0.0771)	(0.205)	(0.207)
1.maleheaded	0.513***	0.522***	-0.375	-0.201
	(0.0922)	(0.0921)	(0.310)	(0.412)
c.age#c.age	-6.66e-05***	-7.39e-05***	0.000132**	0.000238***
	(2.48e-05)	(2.51e-05)	(6.46e-05)	(6.61e-05)
hh_size	0.00635	0.00650	-0.180***	-0.171***
	(0.0131)	(0.0130)	(0.0340)	(0.0322)
education	0.00738	0.00773	0.0661***	0.0834***
	(0.00674)	(0.00668)	(0.0225)	(0.0225)
hh_income_000	0.000257***	0.000252***	0.000215***	0.000286***
	(1.36e-05)	(1.38e-05)	(4.40e-05)	(4.93e-05)
1.stemborer		0.175***	0.180	0.0278
		(0.0603)	(0.198)	(0.204)
1.striga		-0.331***	-0.401*	-0.0663
		(0.0672)	(0.204)	(0.207)
1.other_stress		0.0187	-0.0844	-0.0901
		(0.0601)	(0.162)	(0.155)
ihs_Urea_Kg_Ha			0.130	0.281**
			(0.123)	(0.113)
ihs_DAP_kg_Ha			-0.298**	-0.291**
			(0.131)	(0.125)
seed_kg_Ha			-0.0136**	0.00675
			(0.00647)	(0.00799)
hired_labour_Ha				4.09e-07
				(3.90e-07)
Times_plot_weeded			0.112***	0.158***
			(0.0365)	(0.0391)
1.herbicides_use			1.395***	1.241***
			(0.275)	(0.253)
1.Good_Plot_fertility				-0.489
				(0.303)
1.Medium_Plot_fertility				-0.210
				(0.279)
1o.Poor_Plot_fertility				-
1.Gentle_slope				-0.823*
				(0.446)
1.Medium_slope				-0.878*
				(0.469)
1o.Steep_slope				-
1.shallow_depth_plot				1.647***
				(0.275)

1.medium_depth_plot				-0.277
				(0.255)
1o.deep_depth_plot				-
1.manure_use				-0.751
				(0.501)
0o.irrigated				-
1.intercropping				-0.425**
				(0.168)
Distance				-0.000509
				(0.00412)
1.Tenure				-0.369**
				(0.178)
2.sub_county	0.525***	0.410***	-1.450***	-0.934**
	(0.0920)	(0.0937)	(0.435)	(0.397)
3.sub_county	0.0303	0.0479	0.452	-0.958**
	(0.0987)	(0.0985)	(0.384)	(0.397)
4.sub_county	0.0433	-0.00511	-0.971**	-0.945***
	(0.112)	(0.114)	(0.398)	(0.362)
5.sub_county	-0.710***	-0.922***	-1.238*	-1.061**
	(0.114)	(0.124)	(0.649)	(0.539)
6.sub_county	0.331***	0.325***	-1.646***	-1.397***
	(0.119)	(0.118)	(0.371)	(0.367)
7.sub_county	-1.922***	-1.891***	-3.252***	-3.368***
	(0.143)	(0.144)	(0.459)	(0.437)
9.sub_county	0.268***	0.159*	-0.435	0.0305
	(0.0942)	(0.0964)	(0.520)	(0.448)
12.sub_county	-0.666***	-0.807***	-2.492***	-1.773***
	(0.126)	(0.131)	(0.537)	(0.517)
13.sub_county	0.557***	0.447***	-1.881***	-1.029*
	(0.125)	(0.126)	(0.670)	(0.603)
ihs_hired_labour_Ha			0.0420***	
			(0.0161)	
Constant	8.476***	8.641***	12.06***	11.55***
	(0.165)	(0.171)	(0.721)	(0.887)
Observations	4,806	4,806	399	399
R-squared	0.168	0.173	0.586	0.673
AIC	19660.4	19637.6	1414.3	1339.2
BIC	19764.0	19760.7	1514.0	1474.8

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix 1F: HDDS mothers (24 hours recall) estimation, score

VARIABLES	(1) Household Charactristics	(2) Household characteristics and plot shocks	(3) Household characteristics plot shocks and plot investments	(4) Household characteristics plot shocks plot investments & plot characteristics
1.Affected	-0.323***	-0.136***	-0.752***	-0.855***
	(0.0456)	(0.0480)	(0.159)	(0.156)
1.maleheaded	0.0318	0.0493	-0.520***	-0.722***
	(0.0580)	(0.0574)	(0.179)	(0.158)
c.age#c.age	-9.39e-05***	-0.000105***	-9.01e-05**	-2.30e-05
	(1.30e-05)	(1.30e-05)	(3.94e-05)	(3.72e-05)
hh_size	0.0230***	0.0205***	0.133***	0.138***
	(0.00744)	(0.00734)	(0.0261)	(0.0254)
education	0.0189***	0.0184***	0.00913	0.0234*
	(0.00392)	(0.00389)	(0.0163)	(0.0141)
hh_income_000	0.000213***	0.000223***	7.05e-05**	8.90e-05***
	(9.15e-06)	(9.33e-06)	(3.35e-05)	(3.33e-05)
1.stemborer		-0.254***	-0.386***	-0.349***
		(0.0387)	(0.119)	(0.131)
1.striga		-0.451***	-0.786***	-0.659***
		(0.0433)	(0.161)	(0.151)
1.other_stress		0.132***	0.330**	0.462***
		(0.0385)	(0.129)	(0.132)
ihs_Urea_Kg_Ha			-0.0717	-0.0106
			(0.100)	(0.0981)
ihs_DAP_kg_Ha			-0.150	-0.178*
			(0.103)	(0.101)
seed_kg_Ha			-0.00377	-0.00193
			(0.00384)	(0.00397)
hired_labour_Ha				1.34e-07
				(2.69e-07)
Times_plot_weeded			-0.197***	-0.154***
			(0.0349)	(0.0350)
1.herbicides_use			0.902***	1.021***
			(0.176)	(0.177)
1.Good_Plot_fertility				0.0106
				(0.212)
1.Medium_Plot_fertility				0.432*
				(0.222)
1o.Poor_Plot_fertility				-
1.Gentle_slope				-2.288***
				(0.322)
1.Medium_slope				-2.544***
				(0.315)
1o.Steep_slope				-
1.shallow_depth_plot				0.126
				(0.190)
1.medium_depth_plot				-0.661***

				(0.148)
1o.deep_depth_plot				-
1.manure_use				0.339
				(0.672)
1.irrigated				0.0475
				(0.258)
1.intercropping				-0.0903
				(0.135)
Distance				-0.00554***
				(0.00138)
1.Tenure				-0.568***
				(0.139)
2.sub_county	0.0175	-0.204***	-0.868***	-1.005***
	(0.0657)	(0.0672)	(0.220)	(0.212)
3.sub_county	-0.344***	-0.356***	-0.527**	-0.901***
	(0.0606)	(0.0592)	(0.207)	(0.247)
4.sub_county	-0.795***	-0.832***	-0.558	-0.745**
	(0.0701)	(0.0697)	(0.344)	(0.322)
5.sub_county	-0.285***	-0.601***	-2.660***	-2.720***
	(0.0707)	(0.0755)	(0.367)	(0.365)
6.sub_county	0.326***	0.296***	0.00207	-0.221
	(0.0684)	(0.0694)	(0.197)	(0.196)
7.sub_county	-0.159*	-0.107	-1.599***	-1.907***
	(0.0903)	(0.0895)	(0.321)	(0.342)
9.sub_county	-0.0322	-0.199***	-0.788***	-0.886***
	(0.0670)	(0.0679)	(0.199)	(0.193)
12.sub_county	0.322***	0.0834	-1.813***	-1.790***
	(0.0781)	(0.0793)	(0.218)	(0.214)
13.sub_county	-0.193**	-0.382***	-1.018**	-1.235***
	(0.0815)	(0.0832)	(0.400)	(0.308)
ihs_hired_labour_Ha			0.0371***	
			(0.00946)	
11.sub_county	-0.409***	-0.326***		
	(0.0499)	(0.0741)		
Constant	6.196***	6.471***	9.479***	12.23***
	(0.103)	(0.105)	(0.560)	(0.600)
Observations	8,751	8,751	804	804
R-squared	0.110	0.127	0.270	0.335
AIC	33309.3	33145.2	3014.5	2961.7
BIC	33429.6	33286.8	3131.8	3130.5

Appendix 1G: HDDS mothers (7 days recall) estimation, score

VARIABLES	(1) Household Charactristics	(2) Household characteristics and plot shocks	(3) Household characteristics plot shocks and plot investments	(4) Household characteristics plot shocks plot investments & plot characteristics
1.Affected	-0.171***	-0.114**	-0.828***	-0.871***
	(0.0475)	(0.0518)	(0.162)	(0.139)
1.maleheaded	0.461***	0.473***	-0.372*	-0.617***
	(0.0613)	(0.0613)	(0.197)	(0.234)
c.age#c.age	-0.000103***	-0.000112***	6.36e-05	0.000155***
	(1.42e-05)	(1.42e-05)	(4.57e-05)	(4.23e-05)
hh_size	-0.00245	-0.00432	0.0456*	0.0439*
	(0.00796)	(0.00792)	(0.0272)	(0.0245)
education	0.00813**	0.00793*	0.0503***	0.0614***
	(0.00409)	(0.00405)	(0.0159)	(0.0136)
hh_income_000	0.000249***	0.000250***	6.77e-05**	0.000141***
	(9.89e-06)	(1.00e-05)	(2.90e-05)	(2.71e-05)
1.stemborer		0.109***	0.128	-0.0109
		(0.0421)	(0.122)	(0.120)
1.striga		-0.413***	-0.481***	-0.392***
		(0.0467)	(0.150)	(0.135)
1.other_stress		0.0511	-0.0913	0.121
		(0.0409)	(0.120)	(0.113)
ihs_Urea_Kg_Ha			0.336***	0.385***
			(0.120)	(0.115)
ihs_DAP_kg_Ha			-0.519***	-0.447***
			(0.112)	(0.108)
seed_kg_Ha			0.00201	0.0100**
			(0.00448)	(0.00452)
hired_labour_Ha				9.87e-08
				(1.88e-07)
Times_plot_weeded			-0.0869**	-0.0149
			(0.0383)	(0.0371)
1.herbicides_use			1.307***	1.420***
			(0.174)	(0.157)
1.Good_Plot_fertility				0.280
				(0.209)
1.Medium_Plot_fertility				0.253
				(0.205)
1o.Poor_Plot_fertility				-
1.Gentle_slope				-1.651***
				(0.384)
1.Medium_slope				-1.884***
				(0.382)
1o.Steep_slope				-
1.shallow_depth_plot				1.447***
				(0.177)
1.medium_depth_plot				-0.349**
				(0.148)

1o.deep_depth_plot				-
1.manure_use				0.687
				(0.478)
1.irrigated				-0.391
				(0.273)
1.intercropping				0.0291
				(0.125)
Distance				-0.00345**
				(0.00134)
1.Tenure				-0.991***
				(0.132)
2.sub_county	0.613***	0.439***	0.124	-0.176
	(0.0628)	(0.0634)	(0.204)	(0.198)
3.sub_county	0.142**	0.141**	1.196***	-0.134
	(0.0680)	(0.0674)	(0.233)	(0.241)
4.sub_county	-0.384***	-0.435***	-0.487	-0.991***
	(0.0767)	(0.0774)	(0.296)	(0.242)
5.sub_county	-0.331***	-0.591***	-1.086***	-1.416***
	(0.0720)	(0.0780)	(0.364)	(0.341)
6.sub_county	0.885***	0.876***	0.972***	0.351
	(0.0807)	(0.0803)	(0.245)	(0.217)
7.sub_county	-1.074***	-1.044***	-2.168***	-2.709***
	(0.0981)	(0.0982)	(0.303)	(0.312)
9.sub_county	0.687***	0.549***	1.120***	0.565***
	(0.0644)	(0.0656)	(0.193)	(0.182)
12.sub_county	-0.234***	-0.421***	-0.911***	-1.068***
	(0.0795)	(0.0828)	(0.254)	(0.255)
13.sub_county	0.515***	0.344***	-0.0516	-0.432
	(0.0862)	(0.0879)	(0.380)	(0.296)
ihs_hired_labour_Ha			0.0405***	
			(0.0113)	
11.sub_county	-0.790***	-0.771***		
	(0.0466)	(0.0596)		
Constant	8.359***	8.595***	10.11***	11.79***
	(0.105)	(0.107)	(0.536)	(0.611)
Observations	8,775	8,775	810	810
R-squared	0.156	0.164	0.386	0.510
AIC	34467.7	34390.0	3035.8	2875.4
BIC	34588.1	34531.6	3153.2	3044.5

Appendix 3: Panel Data Estimations

VARIABLES	(1) Fixed Effect _Maize yield	(2) Fixed Effects Insecticide use
1.Affected	-0.127	-0.00837
	(0.102)	(0.177)
1.stemborer	0.0114	0.107
	(0.0876)	(0.127)
1.striga	-0.108	0.163
	(0.111)	(0.162)
1.other_stress	-0.270***	0.00941
	(0.0770)	(0.105)
ihs_Urea_Kg_Ha	0.129***	0.0280
	(0.0431)	(0.0455)
ihs_DAP_kg_Ha	0.0120	0.0565
	(0.0437)	(0.0549)
seed_kg_Ha	0.00564***	0.00986***
	(0.00198)	(0.00356)
1.herbicides_use	-0.470**	-0.203
	(0.195)	(0.208)
ihs_hired_labour_Ha	-0.00782	-0.0121**
	(0.00496)	(0.00540)
Times_plot_weeded	-0.0315**	0.00846
	(0.0153)	(0.0147)
1.manure_use	0.230	0.219
	(0.230)	(0.299)
1.irrigated	-0.0378	-0.526*
	(0.291)	(0.314)
1.intercropping	0.0153	-0.0868
	(0.0737)	(0.106)
Constant	7.088***	0.633**
	(0.164)	(0.270)
Observations	1,445	398
R-squared	0.074	0.163
Number of HHPLOT_ID	753	266

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1