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Effect of Pesticide Use on Crop Production and Food Security in Uganda

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Authors: Linda Nakato, Umar Kabanda, Pauline Nakitende, Tess Lallemant & Milu Muyanga

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Authors

Linda Nakato - Economic Policy Research Centre (EPRC), Makerere University, Kampala, Uganda.
Umar Kabanda - Economic Policy Research Centre (EPRC), Makerere University, Kampala, Uganda.
Pauline Nakitende - Economic Policy Research Centre (EPRC), Makerere University, Kampala, Uganda.
Tess Lallemant - Cornell University, United States.
Milu Muyanga - Michigan State University, United States.

Contact Author:
Linda Nakato
Email: lnakato@eprcug.org/lindanakato@gmail.com
Phone: +256-779-969-861

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ABSTRACT

The increasing pest proliferation has continued to cause a serious threat to food security in Uganda. This study explores the impact of pesticide adoption on food security in Uganda. Specifically, it seeks to assess whether the use of pesticides ensures food security, with crop productivity serving as an intervening variable. Employing the control function approach with fixed effects estimation on a dataset comprising 1,656 households spanning the periods 2013/2014, 2016/2015, and 2018/19 to 2019/20 obtained from the Uganda National Panel Survey, the study reveals several determinants influencing pesticide use in Uganda. The findings also highlight that the adoption of pesticides demonstrates a positive influence on crop productivity. However, when assessed through indicators such as Food Consumption Score (FCS), Minimum Acceptable Household Food Consumption (MAHFP), and Household Dietary Diversity Score (HDDS) at the pre-harvest stage, the results do not indicate a statistically significant correlation of pesticide use and food security outcomes. Consequently, beyond enhanced crop productivity and the pre-harvest activities focused on in the study, it is imperative to consider the post-harvest application of pesticides to comprehensively explain how pesticide use effects food security in Uganda. Based on the positive link between pesticides and crop productivity, its recommended that government should increase awareness on and access of insecticides among farmers. Given that insects are the main pests damaging crops in Uganda. It is also important for Uganda to reform and reactive a regulatory framework having a licensing system to regulate private local market dealers' sale of pesticides. Given that the majority of the households purchase their pesticides from private traders in the local/village market. This approach might improve the quality of pesticide purchased by farmers and, increase pesticide use to diversify produce of more nutritious foods, to ultimately enhance access and nutrient intake per meal in Uganda.

Keywords: Pesticide use, crop productivity, food security.

JEL Classifications: Q00, Q12, D10

EXECUTIVE SUMMARY

Globally, pre-harvest pests damage account for about 35% on average of the potential yield. In Uganda, crop losses due to pests and diseases are estimated at 10-20% (pre-harvest) with an annual loss in monetary terms amounting to US$ 35-200 million (bananas), US$60-80 million (cassava), US$10 million (cotton), and US$8 million (coffee). As a result, this has constrained food access among poor households and the susceptibility to pests and diseases in most of the food insecure regions is a major obstacle to staple food availability, limits food access and leads to food security.

Therefore, adoption of pesticides can prevent large crop losses, raising agricultural output and farm income. Consequently, insufficient attention has been given to empirical research exploring the connections between pesticide use and crop productivity as a critical pathway for ensuring food security. Unlike the numerous studies which have delved into the analysis of factors influencing crop productivity among smallholder farmers in various developing nations, there remains a notable gap in investigating the relationship between pesticide adoption and crop productivity within the context of food security studies.

The empirical gap identified motivates the study to focus on crops such as cassava, maize, beans, ground nuts, and banana (matooke) and assess whether the use of pesticides ensures food security, with crop productivity serving as an intervening variable. Specifically, the research aims to examine the effects of pesticide use on crop productivity, and by extension on food security in the case of Uganda. The study employs the control function approach with fixed effects estimation on a dataset comprising 1,656 households spanning the periods 2013/2014, 2016/2015, and 2018/19 to 2019/20 obtained from the Uganda National Panel Survey.

Finding of this study reveals several determinants influencing pesticide use in Uganda. These include pesticide prices, gender dynamics, mechanization levels, the adoption of improved seedlings, and the incorporation of both organic and inorganic fertilizers. Gender emerged as a significant determinant, highlighting that male-headed households are less inclined to engage in pesticide use. Our analysis also show that the adoption of pesticides demonstrates a positive influence on crop productivity.

Results further show that through indicators such as Food Consumption Score (FCS), Minimum Acceptable Household Food Consumption (MAHFP), and Household Dietary Diversity Score (HDDS) at the pre-harvest stage, there is no statistical correlation between pesticide use and food security outcomes. Consequently, beyond enhanced crop productivity and the pre-harvest activities focused on in the study, it is imperative to consider the post-harvest application of pesticides to complete the explanation of pesticide effect on food security in Uganda.

Based on the positive link between pesticides and crop productivity, government through its collaboration with extension worker and farmers needs to increase on the awareness on and access of insecticides among farmers. Given that insects are the main pests damaging crops in Uganda. It is also

important for Uganda to reform and reactive a regulatory framework having a licensing system which can mandate private local market dealers to attain certification prior to the sale of pesticides. Given that the majority of the households purchase their pesticides from private traders in the local/village market. This expose farmers to counterfeits pesticides on sale due to lack of stringent criterions to license and monitor the sale of pesticides at the village level. This approach might improve the quality of pesticide distributed, diversify pesticide use to produce more nutritious food groups, and ultimately enhance access and nutrient intake per meal in Uganda.

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ACRONYMS AND ABBREVIATIONS

Acronym	Definition
IPC	Integrated Food Security Phase Classification
LSMS-ISA	Living Standards Measurement Study and Integrated Surveys on Agriculture
PARM	Platform for Agricultural Risk Management
UBoS	Uganda Bureau of Statistics
UNHS	Uganda National Household Survey
UNPS	Uganda National Panel Survey

I. Introduction and Motivation

Pests have damaging effects on global, local crop yields and household welfare (Sawicka, 2020). Globally, pre-harvest pests damage account for about 35% on average of the potential yield (Oerke, 2005). In Uganda, crop losses due to pests and diseases are estimated at 10-20% (pre-harvest) with an annual loss in monetary terms amounting to US$ 35-200 million (bananas), US$60-80 million (cassava), US$10 million (cotton), and US$8 million (coffee) (PARM,2017).

Despite the growing incidence of pest-related crop damage, pesticide adoption in Africa remains to be low. Pesticides appear in different forms including fungicides, insecticides, herbicides, and rodenticides (Amaral, 2014). Fungicides are used to destroy fungi, insecticides to kill insects, and herbicides to kill weeds (Mnif, 2014). The most prevalent understanding of pesticides is in terms of chemical classifications, with pesticides being categorized into organic and inorganic constituents. (Kim, 2017). Some evidence finds that farmers experience an increase in food toxification when inorganic ingredients are adopted (Dessart et al., 2019; Knowler and Bradshaw, 2007, Malek et al., 2019; Zimmermann and Britz, 2016). Other shows that pesticides can prevent large crop losses, raising agricultural output and farm income (Popp, et al, 2012). While Africa accounts for only 2-4% of the global pesticide market of US$31 billion (Williamson et al., 2008), the 2019/2020 Uganda National Household Survey (UNPS) in Uganda, reports that only 6% of Ugandan farmers use pesticides. Though the dependence on pesticide is growing significantly in Africa, it is very low in Uganda as compared to other countries like Tanzania, Nigeria, and Ethiopia where according to Sheahan and Barrett (2017) pesticide use stood at 13%, 31%, and 33% respectively.

At regional level in Uganda, for areas located in the Karamoja region, they are more prone to food insecurity and staple food prices are also significantly elevated, with most poor households highly dependent on markets for food (Food Security Outlook, 2023). As a result, this has constrained food access among poor households while staple food prices are also expected to remain high due to high food prices driven by below-average domestic supplies, above-average regional demand, and high fuel prices (Ibid). Similarly, between June and August 2022, an estimated 625,000 people suffered acute food insecurity in Teso (IPC, 2022). Additionally, over 250,000 people were deemed to be in an emergency partly caused by seasonal pests and diseases (ibid). The susceptibility to pests and diseases in most of the food insecure regions is a major obstacle to staple food availability, limiting food access and leading to food security. Indeed, Andersson and Isgren, (2021) cite crops such as cassava, maize, beans, ground nuts, and banana (matooke) as the main five crops affected in other regions of Uganda.

Consequently, insufficient attention has been given to empirical research aimed at exploring the connections between pesticide use and crop productivity as a critical pathway for ensuring food security. While numerous studies have delved into the analysis of factors influencing crop productivity among smallholder farmers in various developing nations (Obasi et al., 2013; Mango et al., 2017; Mekuriaw et al., 2018; Myeni et al., 2019), there remains a notable gap in investigating the relationship between pesticide adoption and crop productivity within the context of food security studies. Notably, research on food security (Sinyolo et al., 2014; Musemwa et al., 2015; Walsh and Van Rooyen, 2015; Sinyolo and Mudhara, 2018) has yet to explore the role of pesticide adoption as a contributing factor to crop productivity and, consequently, food security. The empirical gap identified motivates the study to focus on analyzing the effects of pesticide use on food security. Specifically, the research aims to examine the effects of pesticide use on crop productivity, and by extension on food security in the case of Uganda.

The study uses a panel dataset covering 1,656 households in the period 2013/2014, 2015/2016, 2018/19 and 2019/20. This data is obtained from the Uganda National Panel Survey (UNPS), which is carried out annually with a nationally representative sample of households. The survey is conducted by the Uganda Bureau of Statistics (UBoS) in partnership with the World Bank. In the study, household food security is measured using the Food consumption Score (FCS), Months of Adequate Household Food Provisioning (MAHFP), and Household Dietary Diversity Score (HDDS).

The research reveals that adoption of pesticides has a positive influence on crop productivity. However, when assessed through indicators such as FCS, MAHFP, and HDDS, the results do not indicate a statistically significant relationship between pesticide use and food security outcomes. While the study focus is on pre-harvest activities, a comprehensive understanding of post-harvest application of pesticides and its effect on food security needs to be established to fully explain the overall food security context in Uganda.

The rest of the paper is organized as follows: Section 2 presents the conceptual framework, section 3 examines the data used for the study, section 4 presents the empirical strategy, section 5 presents the study findings and discussions, and section six concludes with a summary and policy recommendations.

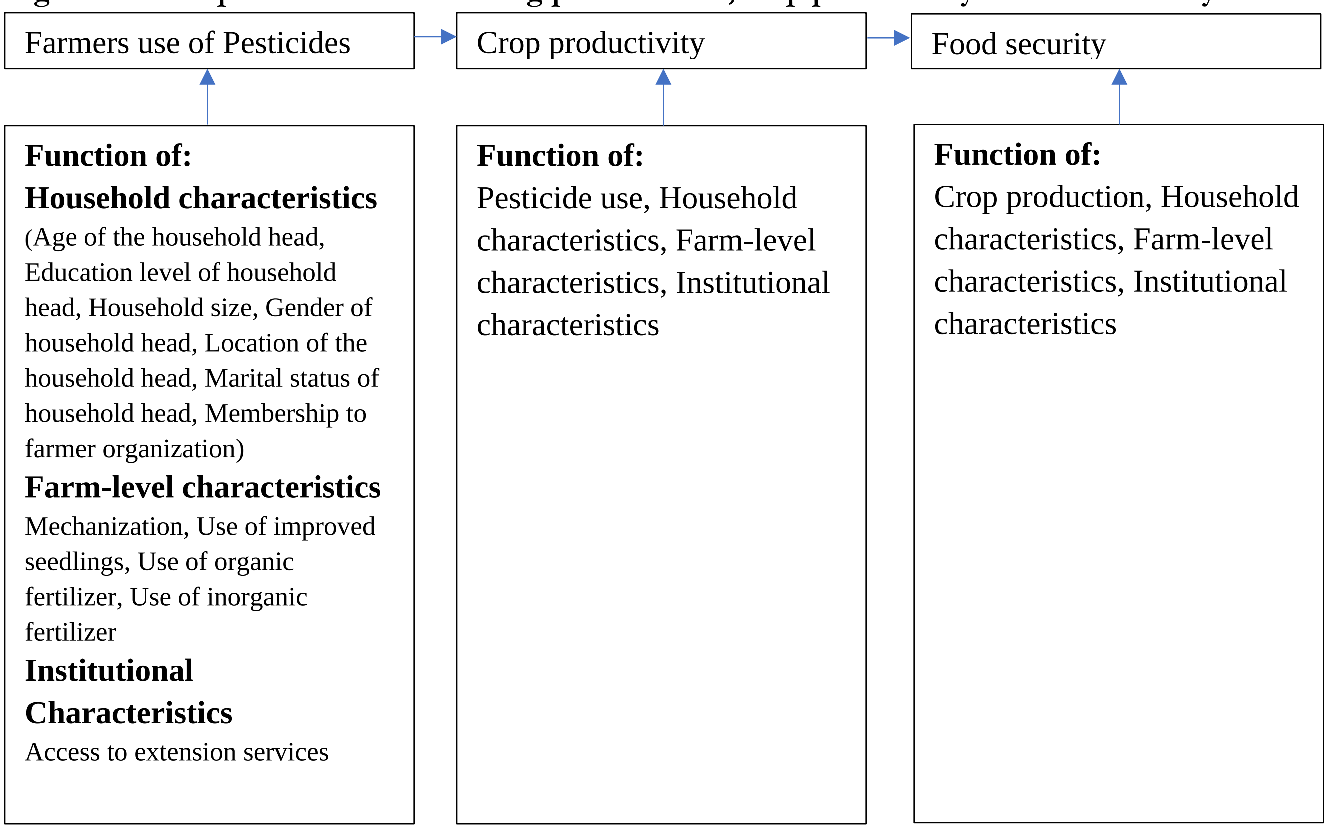
2. Conceptual Framework

Most of the evidence confirm that proper use of pesticides can prevent large crop loss, thus increase crop productivity (Popp et al., 2013). However, there are persistent barriers to pesticide adoption among farmers such as the limited knowledge on how to manage persistent pests damage on crops (Andersson and Isgren, 2021). This is partly attributed to minimal education of users specifically in regard to the harmful effects of pesticides on crop production (Mubushar, 2019). Some of the farmers have inadequate knowledge about pesticide toxicity, and the majority don't use it appropriately (Oesterlund, 2014). Many farmers misinterpret label instructions (Kaye et al. 2015).). Other determinants confirmed to influence the adoption of pesticide includes gender, age, educational level, farming experience, access to extension services, availability of agrochemical shops, and access to credit (Denkyirah et al., 2016; Sanzidur, 2003; Enete and Igbokwe, 2009).

The link between pesticide adoption and food security is established through examining the effect of crop productivity on food damage (Fenik, 2011). Most of the evidence also confirm that proper use of pesticides can prevent large crop loss, thus increasing crop productivity (Popp et al., 2013). On the contrary, the improper application of pesticides increases the toxification of crops, increasing pesticide residues and lowering the nutrient quality of the food (Grewel et al. 2017).

Several studies confirm that pesticide use has a positive effect on food security (Popp, *et al*, 2012). The link between pesticide adoption and food security is established through examining the effect of crop productivity on food security (Fenik, 2011). Studies also show that adopters of improved pesticides are more likely to be food secure than non-adopters (Feleke *et al*, 2004). In the same direction, the effect of pesticides use on food security and the channel of crop productivity in Uganda is scantly researched. Therefore, this study fills the research gap by adopting the conceptual framework in Figure 1.

Figure 1: Conceptual framework linking pesticide use, crop productivity and food security



Authors construction, 2023

3. Data

This paper uses the Uganda National Panel Survey (UNPS) dataset with the design and implementation supported by the Living Standards Measurement Study and Integrated Surveys on Agriculture (LSMS-ISA) project through the Uganda Bureau of Statistics (UBoS) with agricultural households dealing in crops as the target sample. The UNPS is implemented annually and is carried out at a national level with a representative sample of households. The survey is conducted in two visits per wave to capture agricultural outcomes associated with the country's two cropping seasons.

Therefore, each household is interviewed twice a year in visits approximately six months apart. The study considers the four most recent waves of 2013/14, 2015/16, 2018/19 and 2019/20. The UNPS has other waves before 2013/2014, however for this study we use waves starting from 2013/2014. This is adopted to reduce the effect of attrition that result from a sample refresh made in 2013/14. For this study, the dataset for this study is an unbalanced panel dataset and focuses on five key commonly prone crops to pests in Uganda, that is cassava, maize, beans, ground nuts, and bananas (matooke).

3.1. Variable Definitions

Food security is proxied by three variables i.e., Food consumption Score (FCS), Months of Adequate Household Food Provisioning (MAHFP), and Household Dietary Diversity Score (HDDS). FCS is a continuous variable calculated based on dietary diversity, food frequency, and nutritional content of various food groups (World Food Programme, 2008). FCS between 0 to 21 signifies poor food consumption, one between 21.5 to 35 signifies borderline food consumption, and greater than 35 signifies acceptable food consumption. MAHFP is a count variable that measures the number of months that a household is able to meet its food needs (Bilinsky and Swindale, 2010). It ranges from 0 to 12 with higher values signifying higher food security status. HDDS is a count variable that shows the number of food groups consumed by a household over a given reference period (Swindale and Bilinsky, 2006). It ranges from 0 to 12 with higher numbers showing more food groups consumed by a household, hence food security. Due to data limitations, the HDDS in this study is based on a seven-day recall period as opposed to a 24-hour recall period.

Pesticide use is captured using is a dummy variable that takes on the value of one if the household used pesticide, and zero if not. As already mentioned, pesticide use does not usually have a direct effect on food security. It however influences food security indirectly through its effect on crop productivity and income. For the purposes of this study, the research investigated the crop productivity channel. Following (Aragon et al., 2022), the study model crop productivity at the farm level rather than the crop/plot level. Farm productivity is defined as the value of total farm production by the area planted in acres. Other control variables include household-level, farm-level, and institutional-level characteristics. Household level characteristics included are age of the household head, education level of the household head, marital status of the household head, household size, gender of household head, membership to a farmer group, and location of the household. Farm-level characteristics include mechanization, use of improved seedlings, use of organic fertilizer, and use of inorganic fertilizer while institutional-level characteristics include access to extension services.

Table 1 presents key variable definitions and summary statistics. The sampled households have experienced decreasing food consumption score and household dietary diversity score over time. The FCS slightly decreased from 51.28 in 2013/14 to 48.71 in 2019/20. However, even with this decreasing FCS, the households are generally still food secure. On the other hand, the HDDS has decreased from 8.34 in 2013/14 to 1.59 in 2019/20 which signifies that households on average consume less food groups over time. Specifically in 2019/20, sampled households consumed foods from approximately two food groups. The MAHFP has been relatively stable over time showing that households are food secure as they have access to food for over 11 months in a year.

The crop productivity was 8,334 kgs per acre but reduced over the years to 6,512 kgs per acre. We observe a general increase in pesticide use from 19 percent in 2013/14 to 25 percent in 2019/20. The household size was relatively stable between 2013/14 and 2018/19 with approximately five household members. However, there was a marked decrease in the household size in 2019/20 with an average household having one member.

The median pesticide price, proportion of males, household age, marital status of household head, education level of household head, the proportion of households in the urban areas, inorganic and organic fertilizer use, and use of improved seedlings have remained relatively stable over time.

Generally, there is a decline in farmer group membership, household access to extension services, and use of machines.

Table 1: Descriptive statistics

Variable	Description	Mean				
		2013/14	2015/16	2018/19	2019/20	Overall
FCS	Food Consumption Score	51.28	49.16	49.24	48.71	49.75
MAHFP	Months of Adequate household Food Provisioning	11.29	11.49	11.52	11.57	11.45
HDDS	Household Dietary Diversity Score	8.34	3.19	1.90	1.59	4.19
Overall crop productivity	Farm crop productivity in kgs per acre	8,334	7,947	7,483	6,512	7,698
Pesticide	1 if the household uses pesticides and 0 otherwise	0.19	0.19	0.28	0.25	0.22
Pesticide price	The median price of pesticides at the sub-county level	16,829	17,631	16,680	16,447	16,949
Household size	Number of members in the household	5.03	5.16	5.29	1.00	4.39
Gender	1 if the household head is a male and 0 otherwise	0.31	0.28	0.30	0.28	0.29
Age	The age of the household head	48.31	48.08	50.05	51.36	49.21
Married	1 if the household head practices monogamy and 0 otherwise	0.74	0.78	0.75	0.75	0.76
Degree and above	1 if the household head highest level of education is less degree and above and 0 otherwise	0.00	0.01	0.01	0.01	0.01
Urban	1 if the household is located in an urban area and 0 otherwise	0.07	0.09	0.10	0.08	0.09
Organic Fertilizer	1 if the household uses organic fertilizer and 0 otherwise	0.14	0.14	0.18	0.20	0.16
Inorganic fertilizer	1 if the household uses inorganic fertilizer and 0 otherwise	0.08	0.09	0.10	0.12	0.09
Farmer group membership	1 if the any household member belongs to a farmer group and 0 otherwise	0.11	0.09	0.03	0.03	0.07
Extension services	1 if the household has access to extension services and 0 otherwise	0.22	0.16	0.09	0.09	0.15
Mechanization	1 if the household uses any machine and 0 otherwise	1.00	1.00	0.23	0.23	0.68
Seedlings	1 if the household uses improved seedlings and 0 otherwise	0.25	0.27	0.22	0.21	0.24

4. Estimation Strategy

To actualize the conceptual framework illustrated in Figure 1, the research develops a theoretical model linking pesticide adoption and food security while accounting for the mediating role of crop productivity.

There are mainly two issues considered when specifying the econometric models to be estimated: First, pesticide use is likely to influence food security indirectly through its effects on agricultural production and household income. Second, pesticide use is potentially endogenous in agricultural production and household income models. The study uses the control function approach suggested by Wooldridge (2010) to circumvent the endogeneity problem. Considering these two issues, research suggest the following estimation strategy:

First stage estimation of pesticide use model on a vector of covariates where at least one of them is a plausible instrumental variable. The study uses pesticide prices as an instrumental variable as they influence the use of pesticides but do not directly influence crop productivity. Pesticide price is calculated as the value of purchased pesticides in Uganda shillings divided by the quantity of purchased pesticides. Because we can only observe prices for households that purchased pesticides, the research uses the median price at sub county level to fill up for households that did not purchase or use pesticides.

Second stage follows the estimation of crop production model whereby pesticide use enters as a covariate while controlling for its potential endogeneity. Third stage estimation uses food security models. Consequently, we estimate the following models:

First stage: Pesticide use equation.

$$I_{it} = Z_i \delta + \varepsilon_{it} \tag{1}$$

Second stage: Crop productivity equation

$$Y_{it} = I_{it}\rho_{11} + X_{1,it}\eta_1 + \theta_1 \hat{\varepsilon}_{it} + c_{1,i} + \mu_{1,it} \tag{2}$$

Third stage: Food security equation (indicators of food security)

$$C_{it} = \hat{Y}_{it}\alpha_i + X_{2,it}\eta_2 + c_{3,i} + \mu_{3,it} \tag{3.6}$$

In the first stage, the study estimates the pesticides use equation (1). The model on the pesticide adoption decision is a binary choice where the farmer can choose to adopt the use of pesticides or not. A household that decides to adopt pesticide use or not is based on a latent outcome (i.e., the net benefit they will derive from the use). The research observes pesticide adoption status of the household, but there are certain preferences of the household that the study does not observe for example, farmers expectations from the adoption or non-adoption like the net yield anticipated from either using or not using pesticides. In equation (1), I is a binary variable that takes on the value of 1 if a household has used pesticide in time t and 0 otherwise, Z is all observable factors that influence the use of pesticides, such as pesticide price, household and farm-level characteristics (e.g. age of the household head, education level of household head, household size, gender of household head, location of the household head, mechanization, use of improved seedlings, use of organic fertilizer, use of inorganic fertilizer).

In the second stage, model (2) is estimated. The dependent variable is crop productivity (Y), I is as defined in the first stage, X is a vector of control variables as contained in Z in equation (1) with the exclusion of pesticide price. The study also includes the residuals ($\hat{\varepsilon}$) from the first stage pesticide use estimation to eliminate endogeneity concerns between pesticide use and the error term (μ). In the third stage, the dependent variable (C) captures food security measured using the FCS, MAHFP, and HDDS. The research includes the predicted crop productivity ($\hat{Y}$) from the second stage crop productivity estimation as a proxy for the household productivity expectations.

The second and third-stage models are estimated using fixed effects based on results from the Hausman test that favor fixed effects over random effects. Both models are generated using bootstrap standard errors with 50 replications since they involve generated regressors.

5. Findings and Discussion

5.1. Descriptive

5.1.1 Overview of Pesticide Use in Uganda

Generally, the share of agricultural households that use pesticides has been fluctuating over time and in Figure 2 the study observes an increase from 19.49 percent in 2015/2016 to 27.81 percent in 2018/19. However, there is a marked reduction of pesticides use between the two waves from 27.81 percent in 2018/19 to 24.69 percent in 2019/20.

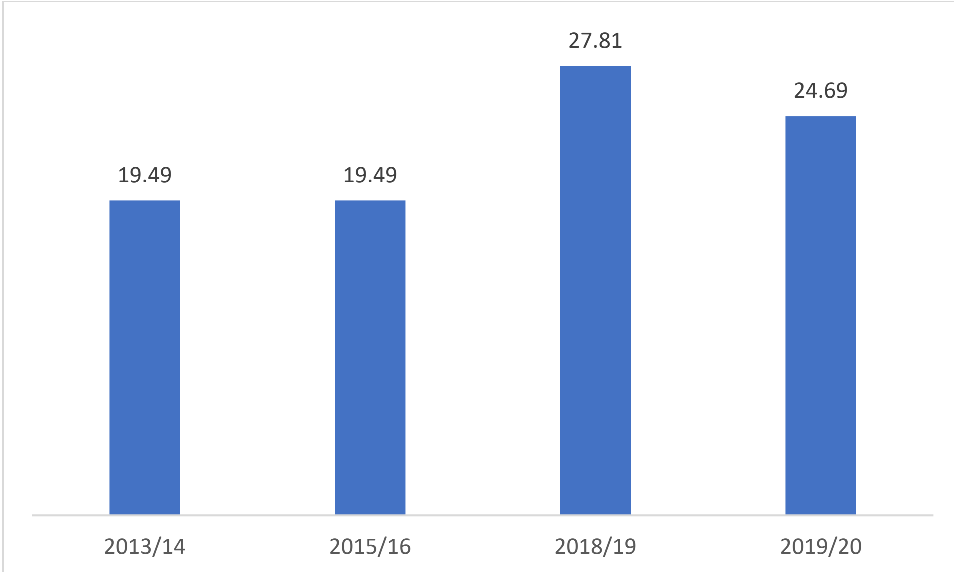


Figure 2: Share of households that use pesticides
Source: Authors construction, (UNPS DATA)

Over the years, the majority of those that use pesticides often use insecticides closely followed by growth regulators and harvest aids (Figure 3). This suggests that the primary pests affecting crops manifest as insects, and pesticides are employed to manage them by either eliminating or deterring their undesirable and destructive behaviors that pose a threat to food production. This aligns with the findings of Bayiyana et al. (2023), who elucidated that the prudent application of systemic insecticides during planting in Uganda proved to be the most economically efficient method for controlling whitefly issues in cassava cultivation.

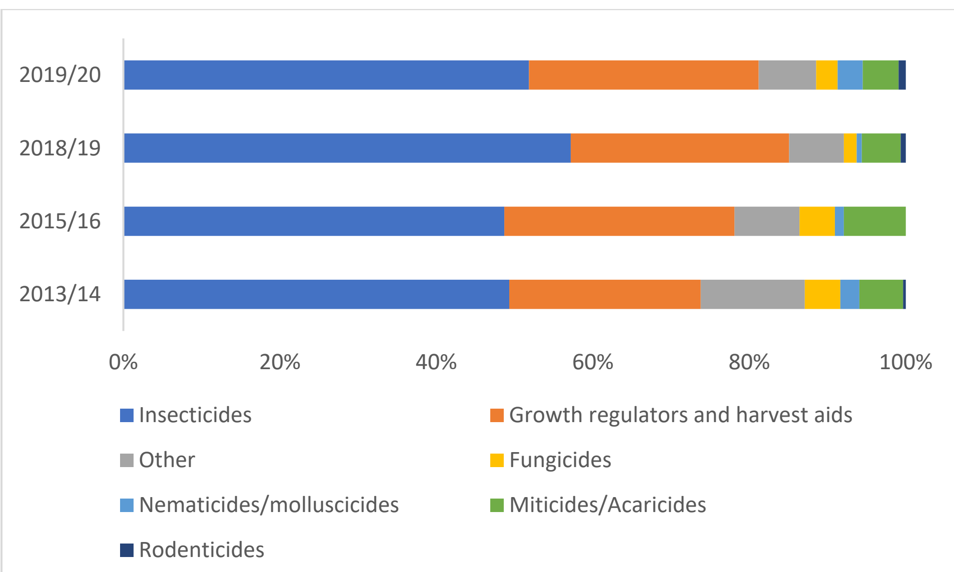


Figure 3: Type of pesticide used by different households
Source: Authors construction, (UNPS DATA)

The UNPS data in the paper shows that 97% of households purchase the pesticides they use. Throughout the waves, the majority of the households source their purchase from private traders in the local/village market followed by private traders in the district market. This signifies that the quality of pesticides sold for income generation is predominantly influenced by individual actors at the local level in village outlets, as opposed to government-led, large-scale financing of pesticide distribution, thus constraining subsidies for high-quality pesticides. This observation is in line with Bergquist's findings in 2022, indicating that household actors in local markets have a comparatively diminished impact on the localized consequences of policy changes. While local prices are less tethered to global prices, this affects the quality of pesticides available to farmers within the context of limited regulatory oversight at village level. This underscores the imperative of regulating the local private actors in pesticide supply chain.

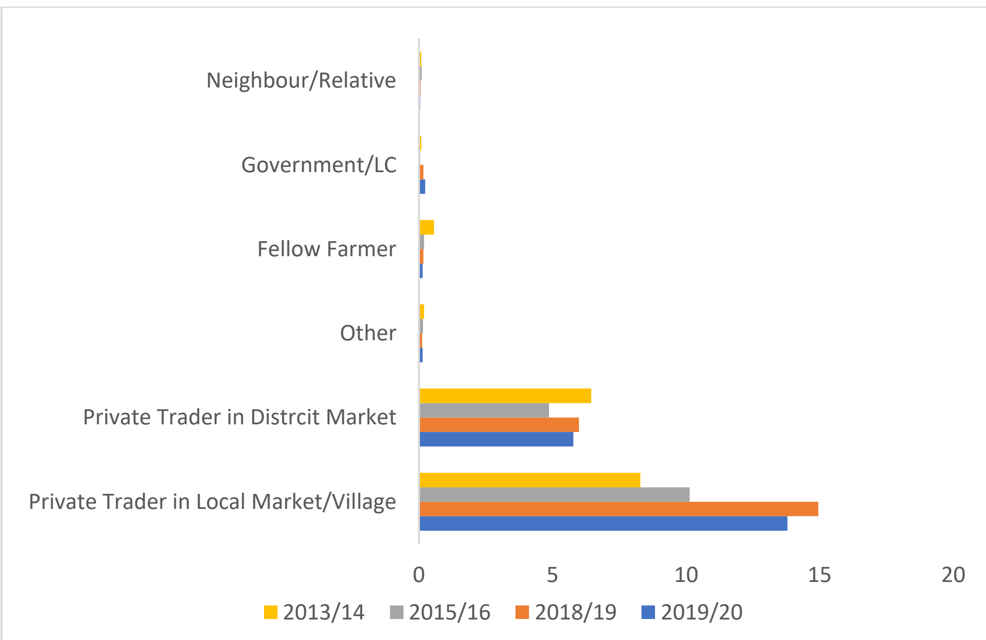


Figure 4: Purchase of pesticides
Source: Authors construction, (UNPS DATA)

5.1.2. Pesticide Use, Food Security and Overall Crop Productivity

We conduct a univariate independent t-tests to compare food security status of households that use pesticides to those that do not use pesticides. We further compare overall productivity of households that use pesticides to that of households that do not use pesticides.
From the results (Table 2), we observe that households that use pesticides are more food secure than those that do not use pesticides. Specifically, households that use pesticides have a higher food consumption score and slightly more months of food provision than those that do not use pesticides. However, there is no difference in the Household Dietary Diversity Score for the different households.

The results further show that households that use pesticides have a significantly higher crop productivity than households that do not use pesticides. We cannot, however, conclude based on the univariate findings and we seek to test our hypotheses in a multivariate setting.

Table 2: Results of univariate t-tests

	Pesticide use = Yes		Pesticide use = No		
	Mean	Obs.	Mean	Obs.	t-stat
Food security					
FCS	52.438	N = 905	48.973	N = 3143	-5.243
MAHFP	11.600	N=905	11.407	N = 3143	-3.712
HDDS	4.218	N = 905	4.178	N = 3143	-0.319
Crop productivity					
Overall crop productivity (kgs/acre)	10286.22	N = 905	6952.799	N = 3143	-6.428

5.2. Empirical Results

5.2.1. First Stage Estimation: Determinants of Pesticide Use

The results show that pesticide price, gender, extension services, mechanization, seedlings, and organic and inorganic fertilizer use are significant determinants of pesticide use in Uganda. Specifically, pesticide price and gender have a negative and significant relationship with pesticide use. This means that as the price of pesticides increases, its use decreases. It should however be noted that the coefficient on pesticide price bears little economic significance. This empirical finding aligns with Ayu's (2019) elucidation, demonstrating that pesticide prices exert a noteworthy and adverse influence on pesticide utilization. Furthermore, Rahman's (2003) assertion underscores the expectation that alterations in pesticide prices are likely to correspond with concomitant changes in pesticide usage patterns.

Concerning gender dynamics, the study outcomes indicate a reduced propensity for pesticide adoption in households headed by males, reflecting a coefficient of 0.234. This trend is ascribed to the predominant role of men as primary decision-makers in agricultural contexts. Consequently, decision-making processes lean towards embracing pest management strategies that emphasize sustainability and cost-effectiveness, with a preference for approaches minimizing reliance on chemical pesticides. Contrarily, Atiku (2022) shows that women are inclined to use fewer pesticides due to being susceptible to experiencing acute-to-chronic health issues arising from pesticide exposure.

Extension services, mechanization, seedlings, and organic and inorganic fertilizer use have a positive relation with pesticide use implying that households that have access to extension services, use machines, use improved seedlings, use organic fertilizer, and use inorganic fertilizer are more likely to use pesticides. Access to extension services provides farmers with knowledge of the different existing technologies such as pesticides that increase their chance of applying such technologies. Moreover, households that are open to adopting one technology are more likely to adopt different technologies.

Indeed, the results highlight that households that adopt Sustainable Agricultural Practices (SAPs) such as mechanization, improved seedlings, organic and inorganic fertilizers are more likely to use pesticides. Nonetheless, the limited acceptance of contemporary SAPs and use of pesticides can be linked to variations in technology preferences, cultural acceptability, and the appropriateness of a specific technology for tasks within women's agricultural activities (Quisumbing and Pandolfelli, 2010; Doss and Morris, 2001). Table 3 shows the results of the first stage estimation of the determinants of pesticide use (Equation 1).

Table 3: Determinants of pesticide use (Logit estimation)

Variables	Pesticide
Pesticide price	-0.000018***
	(4.04e-06)
Gender (Male=1)	-0.234*
	(0.128)
Age (Household head)	-0.004
	(0.017)
Age squared	5.47e-06
	(0.000)
Married (Household head)	0.039
	(0.142)
Degree (education level of household head)	-0.202
	(0.405)
Urban	-0.093
	(0.154)
Household size	0.013
	(0.019)
Farmer Group	-0.052
	(0.186)
Extension services	0.241*
	(0.139)
Mechanization	1.254***
	(0.136)
Seedlings	0.789***
	(0.096)
Organic fertilizer	0.457***
	(0.106)
Inorganic fertilizer	1.708***
	(0.131)
Year dummies	Yes
Constant	-2.697***
	(0.440)
R-square	0.1527
X2	507.33***
Observations	4,048
Number of households	1,656

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

5.2.2. Effects of Pesticide Use on Crop Productivity

Table 4 reports the fixed effects regression results of the effect of pesticide use on crop productivity in Uganda. The coefficient of the first stage pesticide residuals equation is significant which shows that pesticide use is potentially endogenous in that model.

The results show that crop productivity is positively and significantly associated with pesticide use. In other words, pesticide use is associated with an increase in crop productivity. A unit increase in pesticide use increases crop productivity by 1.805 kgs per acre. This aligns with Fanzo's (2014) assertion that the adoption of pesticides enhances crop productivity, thereby reduce pest damage, and increase overall food availability. However, Wordofa (2020) supplements by emphasizing that the application of pesticides regarding HDDS can enable farmers to cultivate nutrient-rich crops and dietary diversity is instrumental in improving per capita calorie intake. Ntakyo (2019) adds that that in Uganda, the more commercialized a household is, the more likely to consume less of the required calories per adult, equivalent per day.

Besides pesticide use, the study confirms that inorganic fertilizer use also influences crop productivity. However, crop productivity decreases with inorganic fertilizer use. Specifically, households that use inorganic fertilizer exhibit a 62.4 percentage point reduction in crop productivity compared to households that do not use inorganic fertilizer.

Table 4: Fixed effects estimation results for overall crop productivity

Variables	Log of Overall Crop Productivity
Pesticide	1.805***
	(0.653)
Gender (Household head)	0.105
	(0.445)
Age (Household head)	-0.078
	(0.071)
Age_sq	0.001
	(0.001)
Married (Household head)	-0.179
	(0.289)
Degree (education level of household head)	-0.065
	(2.032)
Urban	0.229
	(0.320)
Household size	-0.005
	(0.032)
Farmer Group	0.016
	(0.325)
Extension services	-0.039
	(0.238)
Mechanization	0.005

Variables	Log of Overall Crop Productivity
	(0.272)
Seedlings	-0.093
	(0.193)
Organic fertilizer	0.237
	(0.216)
Inorganic fertilizer	-0.624*
	(0.319)
First-stage pesticide residuals	-0.531**
	(0.247)
Year dummies	Yes
Constant	9.934***
	(1.930)
Observations	4,048
Number of households	1,656
R-squared	0.148

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

5.2.3 Effect of crop productivity on food security

Table 5 presents the results for the effect of crop productivity on food security as measured by the FCS, MAHFP and the HDDS. Column 1 reports results pertaining to the Food Consumption Score (FCS), column 2 contains results for Months of Adequate Household Food Provisioning (MAHFP), and column 3 contains results for the Household Dietary Diversity Score (HDDS).

The research indicates that there is no significant correlation between crop productivity and food security, as evidenced by the expected productivity variable derived from the second-stage productivity model. This suggests that the use of pesticides does not indirectly impact food security through the channel of crop productivity. Consequently, although an increase in crop yield potential is often linked to heightened vulnerability to pest attacks, resulting in varying absolute gains and losses (Oerke et al. 1994), the post-harvest management of food, encompassing transport, storage, processing, and packaging quality poses a risk to the availability of food.

While applying pesticides can effectively manage high yields, ensuring the availability of food after harvesting becomes crucial. The study highlights a gap in the development of crop protection measures to prevent and control post-harvest losses during storage for food security to be guaranteed. Instead, the focus has primarily been on pre-harvest losses and addressing the impact of pests on crop production in the field. The study emphasizes the importance of examining the entire food chain, extending beyond crop production and preharvest activities, to mitigate post-harvest losses that undermine food security. This holistic approach is crucial to ensure that the substantial quantities produced from the application of pesticide at both pre- and post-harvest can be preserved, ultimately guaranteeing food security (Popp 2011).

Table 5: Fixed effects estimation results for food security

Variables	FCS	MAHFP	HDDS
Expected productivity	-1.045	-0.017	-0.131
	(2.707)	(0.017)	(0.089)
Gender (Household head)	-2.931	0.041**	0.095
	(1.969)	(0.016)	(0.064)
Age (Household Head)	-0.368	-0.007**	-0.002
	(0.389)	(0.003)	(0.016)
Age squared	0.004	0.000**	0.000
	(0.003)	(0.000)	(0.000)
Marital status of household head			
Married	8.087	-0.008	0.146
	(5.631)	(0.018)	(0.174)
Divorced/separated	-2.049	0.004	-0.071
	(5.884)	(0.023)	(0.190)
Widow/widower	4.540	-0.007	0.0312
	(5.994)	(0.020)	(0.194)
Education level of household head			
Primary	0.444	0.024*	0.083
	(2.139)	(0.013)	(0.064)
Secondary	-0.354	0.042**	0.077
	(3.269)	(0.016)	(0.099)
Diploma	-1.736	0.015	-0.024
	(4.604)	(0.021)	(0.128)
Degree	6.739	0.036*	0.190
	(8.577)	(0.021)	(0.239)
Urban	0.025	0.011	0.047
	(1.459)	(0.008)	(0.047)
Household size	0.344*	-0.000	-0.002
	(0.191)	(0.001)	(0.006)
Farmer Group	0.018	0.016**	0.022
	(1.335)	(0.008)	(0.035)
Extension services	-0.796	-0.011	0.016
	(0.942)	(0.008)	(0.029)
Mechanization	2.199	-0.006	0.090
	(1.354)	(0.010)	(0.068)
Seedlings	1.088	0.002	0.064**
	(0.837)	(0.007)	(0.026)
Organic fertilizer	-0.085	0.008	0.066
	(1.199)	(0.010)	(0.048)
Year dummies	Yes	Yes	Yes
First-stage pesticide residuals	0.614	0.003	0.029*
	(0.559)	(0.004)	(0.017)
Observations	4,048	3,639	3,633
R-squared	0.032		
Number of Households	1,656	1,247	1,244

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

Several control variables merit examination. A positive correlation exists between the gender of the household head and food security, as gauged by the Multi-dimensional Assessment of Household Food Security (MAHFP). This implies that male-headed households have higher food security as compared to female-headed households. Similarly, households that have members who belong to farmer groups have significantly higher food security as measured by the MAHFP. In addition, farmer groups provide a platform for members to share agricultural knowledge, techniques, and best practices (Bliss, 2019). This knowledge exchange leads to improved farming methods, increased crop yields, and better resilience to environmental challenges, enhancing overall food security (Tsouvalis, 2000). The results further highlight a negative and significant relation between the age of the household head and MAHFP. This implies that as the age of the household head increased, MAHFP reduced by 0.006. Given the observed average MAHFP for the sample though, this finding has no significant economic effect.

A positive and significant relation is observed between the household head's marital status and food security measured by the FCS and HDDS. This shows that households headed by married heads have higher food security compared to their counterparts.

Furthermore, as household size increases, the FCS increases. A larger household can potentially have more individuals available for agricultural activities and income-generating work. This increased labour force can contribute to higher agricultural productivity and income, improving the household's overall food security. These are anticipated to result in enhanced accessibility to and utilization of food (Mulwa and Visser, 2020; Nkegbe et al., 2017).

Finally, Households that use improved seedlings have significantly higher food security as measured by HDDS. Many improved seedlings are bred to be resistant or tolerant to common diseases and pests. This reduces the risk of crop losses due to infections, ensuring a more stable and thereby guaranteeing a more dependable and stable food supply (Moumni et al., 2020; Kumar and Gupta, 2020).

6. Conclusion and Recommendation

Due to the growing concern about pesticide damage on food security, in Uganda, this paper analyses the effect of pesticide use on crop productivity and food security in the country. Following the random effects regression methodology, analysis of household pesticide adoption and food security was undertaken using panel data on 1,656 households from the Uganda National Panel Surveys covering the period 2013/2014, 2016/2015 2018/19 to 2019/20.

Our analysis reveals that, notwithstanding the escalating menace posed by pest-related crop impairment, the adoption of pesticides in Africa, notably in Uganda, remains disproportionately low. The empirical findings of the study underscore that a mere 22.4% of Ugandan farmers engage in pesticide utilization, presenting a stark contrast to the heightened prevalence of pesticide use observed in other African nations such as Nigeria, and Ethiopia (Sheahan and Barrett, 2017).

While proper application of pesticides has been established to avert considerable crop loss and increase agricultural productivity (Popp et al., 2013), the research reveals pesticide prices, gender dynamics, educational attainment, mechanization levels, utilization of improved seedlings, and the incorporation of organic and inorganic fertilizers as factors that determine its adoption. Gender emerges as the key factor that influence pesticide use by indicating a reduced propensity for pesticide adoption in households headed by males. This is ascribed to the predominant role of men as primary decision-makers and embrace pest management strategies that emphasize sustainability and cost-effectiveness, with a preference for approaches minimizing reliance on chemical pesticides.

The reliance on purchasing pesticides from private traders at the village level potentially compromise quality and standards, given that these transactions often prioritize profit generation and lack regulatory oversight. This also contrasts with government-led initiatives for large-scale distribution that could facilitate access to higher-quality pesticides through subsidies. In light of these findings, it is recommended, that government through its collaboration with extension worker and farmers increase on the awareness and access of insecticides among farmers. Given that insects are the main pests damaging crops and pesticides are employed to manage them by either eliminating or deterring their undesirable and destructive behaviors, this will increase on the knowledge and determination of high-quality insecticide to deter insecticide damage on crops.

The utilization of pesticides demonstrates a positive impact on crop productivity within the context of Ugandan agriculture. Empirical evidence from the study affirms that households engaging in pesticide use exhibit a heightened likelihood of experiencing increased crop productivity. Consequently, the absence of effective pest control measures places farmers at risk of substantial crop losses to pest infestations. In light of these considerations, it is proposed that Uganda reforms and reactive a regulatory framework having a licensing system which mandates private local market dealers to attain certification prior to the sale of pesticides. Given that the majority of the households purchase their pesticides from private traders in the local/village market. This exposes farmers to counterfeits pesticides on sale due to lack of stringent measure to monitor the sale of pesticides at the village level. Such regulatory measures are envisioned to guarantee access to quality pesticides protecting the agricultural produce of farmers from the potential adverse consequences associated with poor quality and improper pesticide use.

However, the overarching findings is that agricultural productivity as measured by various indicators such as food consumption score FCS Month od Adequate Household Food Provisioning (MAHFP) and Household Dietary Diversity Score (HDDs) doesn't exhibit a statistically significant correlation with food security outcome. Consequently, it is inferred that additional variables may contribute to the determination of food security outcomes beyond the singular influence of agricultural productivity at pre-harvest field level. Therefore, it is recommended that further research endeavours be undertaken to explore and analyze other factors that potentially influence food security outcomes, with a food chain view considering both pre- and post-harvest management of food produced to explain food security. Specifically, for future research, it would be interesting to study post-harvest income and post-harvest handling practices as channels of food security as opposed to using only crop productivity adopted in this paper. Anticipated contributions from subsequent researchers are expected to enhance the explanation of the intricate interplay of pesticide use and food security channels and their influence on food security.

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