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Sustainable Agricultural Technologies and Livelihoods of Smallholder Farmers in Uganda

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In sub-Saharan African countries like Uganda, the majority of smallholder farmers rely on agriculture for their livelihood. They face climate shock that poses a more significant challenge to their agricultural practices. This study aims to investigate whether sustainable agricultural technologies at the farm level significantly contribute to smallholder farmers' livelihoods with a focus on crop diversification. The study used the Uganda National Panel Survey (UNPS) 2018-19 data. It employed an econometric model to analyze the impacts of various sustainable agricultural practices on the farmers livelihood index. Results reveal that the livelihood index is distinguished by tropical livestock unit, value of other assets, literacy index, dependency ratio, marital status of the household head as well as the log of maize, cassava and beans yields. The study also revealed that household index was affected by the sex and age of the household head, the use of improved seed, improved cassava varieties, no burning and the use of organic manure. Adopting and using these practices increases yields and income among vulnerable smallholder farmers., These findings highlight the vital need to adopt sustainable agricultural technologies to improve farmers' ability to adapt, increase agricultural productivity and address the problem associated with crop production sustainability. This will help meet the second goal of the sustainable development goals in Africa.

1. Introduction

In sub-Saharan African countries like Uganda, most households from both farm and off-farm sectors depend on agriculture for their livelihood enhancements. Livelihood facets form part and parcel of agricultural sustainability. Liu et al. (2020) referred to livelihood as the sufficient flow and stock of food and nutrition for households to adequately satisfy their needs. Livelihood security refers to the attainable access and ownership of household income and resources to encounter eventualities (Mottaleb and Ali, 2018). Evidence suggests that climate change is emerging as a significant threat to development across Africa (Clay and King, 2019; Teklewold et al., 2017). Agriculture is one of the sectors significantly affected by climate change and variability (Osewe et al., 2021). Seasonality dynamics, increased droughts, increased temperatures, and altered patterns of precipitation and intensity are some extreme weather events evident in southern Africa (Dhankher et al., 2018).
The fundamental question that contains profound policy implications and should be posed is, what can be done to enhance the ability of the poor smallholder farmers to cope with emerging challenges? The sufficient uptake of sustainable agricultural technologies provides essential solutions to these challenges (Fagariba et al., 2018). For instance, enhancing soil fertility, limiting land degradation, and refining livelihoods and yields are possible solutions. Sustainable agricultural practices are the approaches that allow households to achieve current and future food and nutrition needs, healthy livelihoods, and protect the environmental system (Olunusi et al., 2024). Similarly, sustainable agricultural practices at the farm level include crop diversification, enhanced input use, agroforestry, improved crop varieties, and irrigation (Guo et al., 2019).
Declining crop yields, increased agricultural risks, diminishing soil fertility, and environmental degradation are some of the main challenges threatening societal goals of improving food, income, and nutrition security, especially in smallholder farming (Mkonda and He, 2018). This calls for a significant transformation in African agriculture, especially in worst-affected regions like Uganda, to withstand the emerging challenges. An

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acceptable and meaningful change is expected to improve productivity, build resilience to farming systems, improve livelihoods and reduce environmental harm (Smith and Frankenberger, 2018).

This study focuses on crop diversification among smallholder farmers in rural Uganda. It cultivates more than one variety of crops, similar or different breeds, through intercropping or crop rotations (Abegunde et al., 2020). It is projected to be environmentally feasible, pocket-friendly, and a rational approach to limiting smallholder agricultural challenges. It enhances soil fertility, nutrition diversity, yield stability, and controls pests. Therefore, crop rotation or intercropping is considered agriculturally resilient and stable (Hansen et al., 2019).

Further, diversified cropping enhances biodiversity through the cultivation of indigenous crop varieties. Besides, soil fertility enhancement is a crucial pillar of sustainable agricultural systems. As a result, crop diversification improves productivity, resilience, and livelihood outcomes (Makate et al., 2019). The study sought to ask whether sustainable agricultural technologies at the farm level significantly contribute to livelihoods. Despite the theoretical benefits associated with crop diversification often discussed in the literature, no study has attempted to examine the impact of its adoption on productivity and livelihoods in Uganda. No previous research has evaluated the effects of crop diversification, a proxy for sustainable agricultural practice, in smallholder farming in Uganda, mainly focusing on livelihood outcomes. This study adds to the literature on the influence of crop diversification on smallholder farmers in rural Uganda regarding their livelihood enhancement.

2. Background and Data

Uganda is located within Sub-Saharan Africa (SSA), a region dominated by small-scale farmers whose livelihoods predominantly depend on agriculture. Uganda has diverse agro-ecological zones, which creates heterogeneity among the farmers. Besides, temperature and rainfall patterns occur differently in the four main regions of Uganda. The differences in climatic and edaphic factors determine what crops to be grown. For instance, cassava and sorghum production dominate northern Uganda, while bananas are mainly produced in western and central regions. The Eastern region is well known for producing maize and sweet potatoes. Most crops are produced in all regions, but the scale varies. Several sustainable agricultural technologies, such as crop diversification, drought-tolerant improved seeds, and maize-legume intercrop, have been promoted in Uganda. However, the adoption of these technologies is relatively low in Uganda. Despite farmers being aware of these technologies' importance, most have not adopted them increasing the statistics of disadoption.

The study used household-level socio-economic data from the Uganda National Panel Survey (UNPS) 2018-19. The UNPS captures information on demographics, education, housing, markets and services, employment, and agricultural activities at household, community, and plot levels. The agricultural module includes information on access to land, number of plots, plot area, land use, production quantity, and values for a wide range of relevant crops, fruits, and legumes, as well as records on the agricultural practices adopted by the households, including the use of organic and inorganic fertilizer, drainage, improved seeds, and intercropping.

3. Econometric framework and estimation strategies

This study used crop income to measure well-being, given that agriculture is Uganda's primary livelihood source. Besides, crop farming is particularly vulnerable to climate shocks, so using crop income provides a good measure of resilience. Livelihood is a household's crop income per adult equivalent (AE) divided by the poverty line. The poverty line value used in this study was Ush773.925, measured in purchasing power parity. Following an approach proposed by (Adato et al., 2006), the livelihood index was computed by first estimating a regression function using livelihood as the dependent, as presented in Eq(1) below.

$$L = \beta_0 + \beta_1 X + \mu \tag{1}$$

Where L refers to Livelihood β_0 and β_1 are estimated coefficients, X is a vector of explanatory variables, that is Tropical livestock unit, size of agricultural land, value of agricultural assets, livestock income, dependency ratio, literacy index, and log of maize, beans, sweet potatoes and cassava yields while μ is the error term.

The study used Eq(1) to estimate the livelihood index ($\hat{L}$), which captures variables that determine farmers' exposure, sensitivity, and adaptive capacity to climate change, as shown in Eq(2) below. In other words, the study used equation 1 to generate the dependent variable for Eq(2).

$$\hat{L} = \alpha_0 + \alpha_1 Z + \varepsilon \tag{2}$$

In this case, Z refers to a vector of explanatory variables, including household characteristics and adoption of agricultural technologies. The study also included regional dummies in Eq(2). The essence of Eq(2) is to estimate how adopting sustainable agricultural technologies affects the livelihood index while controlling for household characteristics and regional dummies.

4. Econometric Results

The study presents the first step of the economic procedure result in Table 1. The study ruled out multicollinearity since all explanatory variables had a variance inflation factor (VIF) greater than 10. The study also estimated a robust model to correct the possibility of heteroscedasticity. The F-statistics Prob > F=0.000 indicates that all explanatory variables were significant and jointly different from zero.

Table 1: Livelihood regression to calculate Livelihood Index.

Variables	Coef.	R. Std. Err.
Tropical Livestock Unit	-1.5420***	0.4609
Size of Agricultural Land	-0.0057	0.0054
Value of Other Assets	0.0013**	0.0005
Livestock Income	0.0084	0.0090
Dependency Ratio	-0.0309**	0.0145
Literacy Index	0.2954***	0.0460
HHH Married	14.7367***	2.7773
Value of Agricultural Assets	0.2341	0.1352
Log Maize yields	0.0001***	0.0000
Log Beans yields	0.0002***	0.0000
Log Sweet Potato yields	0.0000	0.0008
Log Cassava yields	0.0002 ***	0.0000
Constant	-0.8952	2.9386
Observations	1941	
R-squared	0.1056	
F stat	134.13 ***	

***, **, * significance levels at 1%, 5%, and 10% (N/B. HHH stands for Household head)

The study regressed the livelihood strategies to compute the index and presented the results in Table 2.

Table 2: OLS Regression result for determinants of a Livelihood resilience index

Variables	Coef.	R Std. Err.
HH Characteristics		
HHH Sex	22.1730***	1.1904
HHH Age	-0.3132***	0.0403
Access to Extension	-1.4721	2.0691
Group Membership	10.1199***	3.8975
Agricultural Technologies		
Crop Diversification	1.8698	2.5643
Improved seeds in any crop	8.7476***	2.4198
No burning	3.4355**	1.6700
Used Organic Manure	0.0010***	0.0003
Soil and water management	0.8701	1.5723
Used Pesticides	2.6133	1.6726
Used Inorganic Fertilizer	0.0002	0.0209
Improved seeds of Maize	1.5901	3.2226
Improved seeds of Beans	1.6029	5.5668
Improved varieties of sweet potatoes	16.8113	10.1305
Improved varieties of Cassava	13.4393***	4.0402
Constant	37.6044	3.1363
Observations	1941	
R-squared	0.2229	
F stat	38.25***	

***, **, * significance levels at 1, 5, and 10% respectively (N/B. HHH stands for Household head)

The study found that tropical livestock unit, the value of other assets, dependency ratio, literacy index, whether the household head is married, and log of maize, beans, and cassava yields negatively or positively correlated with the livelihood index characterization among the smallholder farmers in Uganda.

4.1 Effect of Agricultural technologies on resilience to climate change shocks

The study estimated the OLS regression function using the livelihood index computed from the first step regression as the dependent variable. Further, the explanatory variables were agricultural technologies and household characteristics as control variables. Table 2 presents the result of the second regression to establish the effects of farming practices on the livelihood index. The R^2 of 72.2 % and the mean VIF of the coefficients 3.016 implied an excellent fit for the estimated equation. Similarly, household head sex, household head age, membership to a group, improved seeds of any crop, no burning, organic manure application, and improved cassava varieties affected the livelihood resilience index.

4.2 Discussion

The study aimed to estimate the effects of sustainable agricultural technologies on the livelihood resilience index of smallholder farmers in Uganda. Table 1 shows that the tropical livestock unit negatively influences the farmers' livelihood index's computation, though with a significant statistic. The coefficient for the study estimation is negative, indicating that farmers' ownership of animals is diminishing. Conforming with Wossen et al. (2018), relative changes to the tropical livestock unit lead to a direct food insecurity indicator. Farmers becoming food insecure implies that their livelihood index has deteriorated.

The value of other assets characterizes the livelihood index positively and significantly. The more assets a household owns, the less vulnerable they are regarding their livelihood index. Further, augmenting the value of the other assets often increases income options, improving their livelihood. According to Kuang et al. (2019), the more a household increases its human capital and financial capital, the more capable they are of upgrading their living standards and farming technologies.

Consequently, the dependency ratio characterizes the livelihood standards negatively, though with significant statistics. The dependency ratio represents the household structure of the smallholder farmers. Households with a higher livelihood index have low dependency ratios because they sustain income. Jiao et al. (2017) show that the higher the dependency ratio, the lower the livelihood adaptive capacities. Having a higher dependence on a household reduces the ability to react and adapt to the changing shocks to maintain the same living standards. Similarly, literacy level characterizes the household livelihood index positively and significantly. According to Israr et al. (2014), the higher the literacy level in a household, the greater the ability to manage their investments. In other words, highly literate family members can make effective decisions that improve the households' livelihood. The results also indicated that the married household head could characterize the livelihood index positively and significantly. It means married household heads are less vulnerable to shocks than divorced, single, or separated. These sentiments are supported by Rahman and Akter (2014), who observed that the married cluster was more resilient to poor rainfall shocks in South Africa among the household heads. The crop yields (maize, cassava, and beans) characterized the household livelihood index positively and significantly. According to Jezeer et al. (2019), non-farm approaches offer households with capital resources to obtain an enhanced quantity and quality of agricultural equipment, resulting in improved yields. Therefore, an improved crop yield enhances the household's livelihood resilience against shocks and poverty.

The study determined the effects of agricultural technologies on household livelihood index resilience, notably changing climate risks. The study found a positive and significant correlation between the gender of the household head and the household livelihood index resilience. This is because gender influences the capability to participate in specific livelihood approaches. From this study, the gender of the household head is vital, affecting the resilience the whole household's livelihood index. According to Despotaki et al. (2018), the gender of the household head improved the adaptive capabilities of the smallholder farmers. Regardless, Gerlitz et al. (2017) opined that there is a need to understand the complexities between the gender of the household head and the livelihood resilience index, a factor that the study proves.

On the other hand, the age of the household head was observed to have a negative, significant influence on the household livelihood resilience index. For instance, a unit increase in the age of the household head resulted in a 31.2 % decrease in the livelihood resilience index. The study argued that as the farmers become incapable of diversifying to other livelihood approaches to sustain their resilience, they may concentrate on on-farm activities to maximize subsistence consumption. The same concept was supported by Atlin et al. (2017), who concluded that the age of the household age affected livelihood diversification negatively in Ethiopia. However, the study findings were against Guo et al. (2019), who noted that as the household head ages, the larger the household size assists with labor, necessary factor sustaining the livelihood resilience index.

Sina et al. (2019) opined that group membership leads farmers to share knowledge and information ranging from new and sustainable farming technologies to climate adaptation approaches necessary for smallholder farmers to enhance their crop production. Ahmed et al. (2018) also concluded that group membership enhances the generation of social capital, an indicator created as a proxy to measure the quality and quantity of associations in groups. Therefore, household members of certain agricultural groups improve their trust, perception, and social cohesion. The study findings concur with these outcomes. The study observed that smallholder households who are members of the farming groups exhibited a higher livelihood resilience index (Osewe et al., 2021). The study observed different regions influence the livelihood resilience index differently. The study argued that other areas contain different climatic zones and off-farm livelihood strategies.

Adopting and using improved seeds increases yields and income among vulnerable smallholder farmers. Smale et al. (2018) observed that improved seeds of any crop increase productivity thus assisting in poverty alleviation among Sub-Saharan countries. Wossen et al. (2018) also opined that improved seeds were an effective strategy to enhance the farmers' adaptive capacity and meet the second goal of the sustainable development goals in Africa. The study findings concurred with these ideas since there was a significant and positive association between the improved seeds and the livelihood resilience index of the smallholder farmers in Uganda.

No burning is a concept of conservation farming that enhances soil fertility, limits soil erosion, improves nutrient availability, and reduces pests and diseases. It also leads to increased yields and resilient household agricultural production. Osewe et al. (2020) mentioned that a farmer who adopted conservation agriculture gained from the improved soil organic carbon accumulation compared to the conventional farming practices. The study found a positive and significant influence of no burning on the livelihood resilience index of the farmers. Organic manure was also a positive and significant factor in influencing the livelihood resilience index. Organic manure is a sustainable farming method that enhances soil fertility and increases crop yields (Fagariba et al., 2018).

Crop varieties are an essential climate adaptation approach in Sub-Saharan African countries. Atlin et al. (2017) observed that different varieties are required to augment crop productivity depending on regional context. Further, improved crop varieties enhance tolerance to abiotic and biotic stresses. Thus, it is projected to maintain or augment crop yield under stress conditions. Adopting crop varieties can also assist smallholder farmers in coping with climate shocks. As a result, the study also found a positive and significant correlation between the improved cassava varieties and the livelihood resilience index among smallholder farmers. As Lunduka et al. (2019) indicated, crop varieties substantially address the problems associated with crop production sustainability, such as enhancing soil moisture and fertility.

5. Conclusion and Policy Implications

Climate shocks are the significant challenges that smallholder farmers face in sub-Saharan African countries. Improving the farmers' livelihood resilience and augmenting their livelihood approaches are the pillars of dealing with the changing climatic conditions. The study sought to understand the effects of sustainable agricultural technologies on the smallholder livelihood resilience index. The results indicated that the livelihood resilience index was characterised by the tropical livestock unit, the value of other assets, the dependency ratio, the literacy index, whether a household head is married, and the log of maize, beans, and cassava yields. On the other hand, the study found that the factors that affected the household resilience index included the household head sex, age, membership to a group, improved seeds of any crop, no burning, use of organic manure, and improved cassava varieties. Therefore, the study suggests increasing households' adaptive capacity through social safety nets and asset ownership to promote sustainable agricultural practices.

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