Article

Does Crop Diversification Involve a Trade-Off Between Technical Efficiency and Income Stability for Rural Farmers? Evidence from Zambia

Agness Mzyece ¹ and John N. Ng'ombe ^{2,*} ¹ Business Division, Iowa Wesleyan University, Mount Pleasant, IA 52641, USA; agness.mzyece@iw.edu² Department of Agricultural Economics and Extension, University of Zambia, Lusaka 10101, Zambia

* Correspondence: ngombe@okstate.edu

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Abstract: Crop diversification is a climate-smart agricultural technique which helps to improve resilience for farmers in the face of volatile weather due to climate change. Previous research on its effects on technical efficiency has shown mixed results. Despite burgeoning literature on the subject, an important research question that remains uninvestigated is: does crop diversification involve a compromise between technical efficiency and resilience (income stability) for rural farmers? Using nationally representative rural household survey data from Zambia, this study empirically answers this research question. We employ the Data Envelopment Approach (DEA) for efficiency and a two- step least-squares approach for income variability. Our results show evidence that crop diversification significantly improves income stability but significantly reduces technical efficiency. The paper provides useful implications for policies that promote crop diversification in Zambia and other countries.

Keywords: climate-smart agriculture; crop diversification; technical efficiency; income variability; Zambia

1. Introduction

The challenge of meeting the increased demand for food while striving to eradicate hunger and poverty is more daunting in the face of climate change. This challenge is even more serious in Sub-Saharan Africa (SSA) where more than a third of the world's extreme poor live [1] and where at least 65% of the labor force is employed in agriculture [2,3]. As with the rest of SSA, Zambia's agriculture is heavily reliant on rainfall, making the country highly vulnerable to climate change. Wineman and Crawford [4] contend that at least 90% of smallholder farmers in Zambia depend on rain-fed agriculture—which exacerbates farmers' exposure to climate change impacts. Mulungu et al. [5] demonstrate that under a worst-case scenario, maize yields in Zambia will decrease by 25% mainly due to temperature increases. Moreover, Hamududu and Ngoma [6] and Mulungu and Ng'ombe [7] suggest that climate change will result in a 13% decline in water availability in Zambia by the end of the century in 2100, thereby posing a much higher risk to most field crops such as maize.

To offset these negative effects from climate change, most governments and international development agencies in SSA have markedly invested in promoting climate adaptation strategies that are associated with improved agricultural productivity among farmers [8,9]. One of the adaptation strategies that the Zambian government outlined in its National Climate Change Response Strategy (NCCRS) is enhancing farming systems that encourage crop diversification [10]. Crop diversification is the practice of cultivating more than one variety of crops in the form of mixed cropping [11,12]. Its advantages are that it can increase yield stability and bring more spatial and temporal biodiversity on the farm [13]. In addition, crop diversification is associated with improved soil fertility, control of pests and diseases, and nutritional diversity [14].

Crop diversification may, however, also entail competition for resources among various crops. For example, over-diversification may place pressure on agricultural land and farm management resources and may therefore reduce farm efficiency. Previous research on the effects of crop diversification on technical efficiency show contrasting results. Manjunatha et al. [15] analyzed the impact of crop diversity, among other factors, on farm profit and efficiency using 90 groundwater irrigated farms in South India. They found that crop diversification is significantly and negatively associated with inefficiency. Ogundari [16] examined the effect of crop diversification on technical efficiency in Nigeria and found that crop diversification increases technical efficiency. Ajibefun [17] suggested that crop diversification leads to improved technical efficiency because, under multiple cropping systems, although crops compete for nutrients, they also mutually benefit through soil fertility and a reduction in diseases, weed, and insects. Rahman [18] observes significant efficiency gains from diversification among cropping enterprises in Bangladeshi. Moreover, a study by Coelli and Fleming [19] find that crop diversification significantly improves technical efficiency among farmers in Papua New Guinea.

However, Llewelyn and Williams [20] conclude that technical efficiency among Indonesian farms is significantly reduced as a result of crop diversification. Likewise, Haji [21] finds that crop diversification significantly reduces both allocative and economic efficiency in Ethiopian farms. Mixed results on the effects of crop diversification on farm efficiency supports the assertion by Rahman [18] that individual developing economies are likely to demonstrate heterogeneous relationships between crop diversification and production efficiency. This entails that the outcome of the effect of crop diversification on technical efficiency may be region specific. There is therefore a need to examine the effects of crop diversification on technical efficiency and other farm performance outcomes. Income variability, as a performance outcome, is specifically of interest because it shows how resilient farm households are to shocks.

Previous research on the effects of crop diversification shows that crop diversification significantly reduces income variability [22–24], thereby supporting the idea of it being a resilience strategy. In the context of Zambia, Arslan et al. [25] found that crop diversification has no statistically significant effect on reducing income risk while Maggio et al. [26] found that diversification significantly reduces income variability in certain cases. Other crop diversification studies in the context of Zambia have focused on the factors affecting the adoption and extent of crop diversification, rather than its effects [27,28].

Previous research has, however, examined the effects of crop diversification on technical efficiency independently from its effects on income variability. That is, the interaction of these effects on the same decision maker (farmer) has not been clearly examined. Such an analysis could provide valuable insights into the decision-making process faced by a farmer who has either adopted or is considering adopting crop diversification based on whether diversification entails a trade-off between technical efficiency and income stability. In the case of a trade-off, policy makers may need to bundle crop diversification recommendations with other strategies that eliminate or minimize the trade-off. This research, therefore, examines the effects of crop diversification on technical efficiency and income stability of farming households in Zambia. The objective of the study is to identify the direction and magnitude of effects of crop diversification on technical efficiency and income variability, and therefore bring to light any potential trade-offs or augmented benefits from diversification.

2. Materials and Methods

2.1. Data

We use data from the 2015 and 2012 Rural Agricultural Livelihoods Surveys (RALS), the most comprehensive country-wide surveys for rural farmers in Zambia. RALS is designed and implemented by Indaba Agricultural Policy Research Institute (IAPRI), the Central Statistical Office and Zambia's Ministry of Agriculture.

The 2012 RALS was based on Zambia's 2010 population census sampling frame. It had a sample size of 8840 households randomly sampled using a two-stage stratified sample design. The first stage involved identifying the Primary Sampling Unit (PSU) and the second stage involved identifying agricultural households from a list of all households and stratifying those agricultural households into three categories on the basis of area planted, presence of specified specialty crops and livestock. Thereafter, systematic sampling was used to select 20 agricultural households across the three strata in each PSU. A total of 442 PSUs were covered.

The 2015 RALS was a follow up panel survey to the 2012 RALS. The 2015 RALS had a sample size of 7934 households randomly selected from 476 PSU with a total of 660 new households relative to the 2012 RALS. In 2015, 7254 households were re-interviewed and the attrition rate between 2012 and 2015 was 17.9% due to households having moved out of the area or death. The sampling design used in 2015 was the same as that used in 2012. For more details about the RALS survey design, see [29].

The RALS contains a wide-ranging set of agricultural households' livelihood activities and outcomes. In addition to the detailed agricultural production, post-harvest and crop forecast data which is traditionally collected through the Ministry of Agriculture, the 2015 RALS survey also includes often-scarce information such as off-farm and non-farm labor income, intergenerational transfers, migration, natural resource use and effects of shocks on households.

Our analysis uses cross-sectional data from the 2015 RALS. However, to calculate income variability over time, we utilize household incomes reported in both the 2012 and 2015 RALS. Key variables from the 2015 survey that are used in this study are presented in Table 1 below. Guided by the existing literature, the following independent variables were considered in our analysis. We included age of the household head, as it is related to farming experience and tends to positively impact technical efficiency among farmers [16]. The effect of age on income variability is mixed. Some research suggests a positive effect (Schurle and Tholstrup [30]) attributed to the possibility that older farmers may be less flexible to adjusting to unusual circumstances. Other research has found a non-linear relationship between age and income volatility in which age reduces volatility up to a certain level [31]. We included the gender of the household head to capture the differences in production choices between males and females [21]. Arslan et al. [25] have shown that female-headed households have higher income risks compared to male-headed households. Another important variable that we included is the number of years of education of the household head. We expect that more educated farmers are likely to be more receptive to new technology and therefore expected to have higher levels of technical efficiency [16]. In addition, education has been shown to have a negative significant impact on income risk [25]. We also include household size as it has been shown to have a negative significant impact on technical efficiency due to the under-utilization of labor in the household [21].

Other variables that we considered are value of agricultural assets, access to loans, livestock ownership, off-farm income, use of soil management practices, access to technical information, use of fertilizer and improved seed, and farm size. The value of agricultural assets has been shown to have a positive significant impact on technical efficiency by allowing farmers to use efficiency-enhancing equipment [21]. Assets are also a proxy for wealth which has been shown to reduce income risk [25]. As for access to loans, loans are an extra source of income for purchasing yield-enhancing inputs and/or for risk management. Getting a loan is therefore expected to have a positive significant effect on efficiency and a negative significant effect on income variability. We include livestock ownership in our analysis as livestock is a source of cash, organic manure, draught power and transportation, and is therefore expected to have a positive effect on technical efficiency [21]. As an alternative source of cash, livestock ownership is also expected to reduce income variability. We include off-farm income because it has been shown to have a significant positive effect on technical efficiency by introducing additional income to finance farm activities [21]. It is also a form of risk management which can help to reduce overall income risk [32].

The use of soil management techniques can improve soil conditions leading to improved yields [33] and potentially reducing income variability. As for access to technical information, technical information

may be accessed through channels such as extension visits, meetings, and radio among other sources. We consider access to information in our study because information equips farmers with new knowledge and skills that may be necessary to improve their technical efficiency and resilience [21]. We include the use of fertilizer and improved seeds because both have been shown to significantly affect agricultural yields in Zambia [34,35]. We thus expect the use of fertilizer and/or use of improved seeds to increase and stabilize yields. We include farm size because it has been shown to have a negative significant impact on technical efficiency in the case of a labor-intensive production activity [21]. However, Rahman [18] suggests that farm size has a positive impact on efficiency in the presence of scale economies. Additionally, farm size has also been shown to have a negative significant impact on income variability [25], which highlights its relevance to this study.

Our independent variable of interest is crop diversification and our dependent variables are income variability and technical efficiency. Crop diversification is measured using the Simpson index of diversification (SID), calculated as $SID = 1 - \sum_{i=1}^k \left(\frac{A_i}{\sum_{i=1}^k A_i} \right)^2$, where A_i is the land size allocated to each crop i , $0 \leq SID \leq 1$. The value 0 means no diversification, while 1 means total diversification. To calculate income variability, we use the coefficient of variation of income. The coefficient of variation is defined as the standard deviation of a variable divided by the variable's mean [36]. The coefficient of variation is scale invariant and is also insensitive to units of measurement as compared to the standard deviation or variance [37]. We calculate the coefficient of variation for income from crop revenue between the 2012 and 2015 agricultural seasons.

Technical efficiency is a relative measure of managerial ability for a given level of technology [38]. It is our measure of interest because growing more than one crop requires managing the allocation of resources across different crops. In calculating technical efficiency measures, we use the Data Envelopment Approach (DEA) proposed by Charnes et al. [39].

Table 1. Summary statistics on key variables.

Variable	Description	Mean	Std. Dev.	Min	Max
SID	Index of crop diversification	0.49	0.23	0	1
CV revenue	Coefficient of income variation	140.84	2.94	27.25	141.42
DEA-CRTS	CRTS technical efficiency	0.21	0.26	0	1
DEA-VRTS	VRTS technical efficiency	0.33	0.29	0	1
DEA-NRTS	NRTS technical efficiency	0.22	0.27	0	1
Age	Age in years	49.38	14.55	8	105
Male	1 if Male headed household	0.82	0.39	0	1
Education	Number of years of education	6.02	3.77	0	19
Household size	Number of people living in the household	7.22	2.99	1	30
Agricultural assets	value of agricultural assets owned	1081.13	4480.31	0	157950
Got loan	1 if household got a loan during production year	0.20	0.40	0	1
Livestock	Number of livestock types owned	1.75	1.30	0	7
Off-farm income	Value of off-farm income earned	6506.09	23210.11	0	675000
Soil management	Number of soil management techniques used	2.51	2.12	0	18
Technical information	Number of production issues household received information about	5.44	4.34	0	15
Kg fertilizer	Total Kgs of fertilizer used	338.12	590.30	0	10400
Kg improved seed	Total Kgs of improved seed used	65.62	183.91	0	7523.2
Hectares planted	Hectares of land area cultivated	2.50	2.46	0.01	45.25
N	Number of observations	5571			

We choose the DEA, a non-parametric approach, instead of its counterpart, a stochastic frontier approach, mainly because the DEA has the advantage of not requiring an arbitrary specification of

a functional form or distribution of disturbances as well as being able to easily account for multiple outputs [40].

Consider a vector of outputs y_{in} , for which $i = 1, \dots, I$ outputs. Moreover, let x_{kn} be a vector of inputs for $k = 1, \dots, K$ inputs, and λ be the weights for constructing the frontier (the frontier envelops the data such that all observations lie on or below the frontier). Let θ , the efficiency measure, be the weighted sum of outputs over the weighted sum of inputs. In DEA, a decision making unit is faced with the following optimization problem:

$$\text{Max}_{x_n} \theta \quad (1)$$

subject to

$$\sum_{n=1}^N \lambda_n y_{in} \geq y_{in}' + \theta y_{in}', \quad i = 1, \dots, I \quad (2)$$

$$\sum_{n=1}^N \lambda_n x_{kn} \geq x_{kn}' - \theta x_{kn}', \quad k = 1, \dots, K \quad (3)$$

$$\sum_{n=1}^N \lambda_n = 1, \quad (4)$$

$$\lambda_n \geq 0, \quad n = 1, \dots, M \quad (5)$$

The constraint in Equation (2) implies that the n th farm's i th output will be scaled up by θ to an output level less than or equal to the output generated by the weighted linear combination of farm n 's efficient peers. The second constraint in Equation (3) implies that the n th farm's k th input is scaled down by θ to an input level greater than or equal to the input created by the weighted linear combination of farm n 's efficient peers. The third constraint in Equation (4) relaxes the assumption that all farms are producing at an optimal scale while the fourth constraint in Equation (5) is a non-negativity restriction, which implies that λ , the frontier weights, cannot take non-positive values (that is, both the farm's inputs and outputs are not negative values). A farm is efficient if θ is 0 and is inefficient if $0 \geq \theta \geq \infty$. This formulation is based on Henderson et al. [41].

The DEA can be formulated on the basis of constant returns to scale (CRTS), variable returns to scale (VRTS) or non-increasing returns to scale (NRTS). CRTS is based on Charnes et al. [39]. It assumes that a proportional change in inputs should produce an equal proportional change in inputs. VRTS and NRTS are based on Banker et al. [42]. VRTS assume that a proportional change in inputs can produce an equal or larger proportional change in outputs. NRTS assume that a proportional change in inputs produces a smaller proportional change in outputs. Incorporating economies of scale in the analysis allows us to see how farmers who are considered efficient may gain, lose or maintain a constant level of productivity. Figure 1 illustrates these concepts graphically.

Figure 1. Graphical illustration of constant returns to scale (CRTS), variable returns to scale (VRTS), and non-increasing returns to scale (NRTS).

2.2. Conceptual Framework

The concept of economies of diversification reflects the benefits in terms of cost reduction associated with firms producing multiple outputs [43]. It is an extension of the concept of economies of scope [44] which exists when it is less costly to combine production of goods rather than producing them separately. The underlying theory behind these related concepts is as follows:

Suppose a farmer is producing m outputs using n inputs. The farmer chooses inputs to minimize cost as shown in the cost minimization problem below:

Given that y_i is output for good i , p_i is the price of output i , x_j is the input j and w_j is its price, Y is a vector of outputs $(y_1, y_2, \dots, y_m)$ and X is a vector of inputs $(x_1, x_2, \dots, x_n)$, a farmer maximizes

$$\text{Max} \sum_{i=1}^m p_i y_i - \sum_{j=1}^n w_j x_j \quad (6)$$

subject to

$$Y_i = f(X) \quad (7)$$

Solving this optimization problem, we find the cost function $c(y_i, p_i)$ for a farmer producing one output, and the cost function, $c(Y, P)$ for a farmer producing m outputs. Economies of scope exist if $\sum_{i=1}^m c(y_i, p_i) > c(Y, P)$ or if

$$\frac{\sum_{i=1}^m c(y_i, p_i) - c(Y, P)}{c(Y, P)} > 0 \quad (8)$$

The concept of economies of diversification suggests that, if we break the industry into K specialized firms such that $2 \leq K \leq m$, where $y^k = (y_1^k, \dots, y_m^k)$ is a vector of outputs produced by the k th firm where $k = 1, \dots, K$, and $c(y^k, p)$ is the cost function for the k th firm, then economies of diversification exist if

$$\sum_{k=1}^K c(y^k, p) > c(Y, P) \quad (9)$$

In this study, we hypothesize that economies of scope and diversification exist because farmers use increasingly less inputs to produce additional crops. Thus, our a priori expectation is that crop diversification among farmers increases technical and cost efficiency. Due to lack of data on input prices, we only focus on the effect of crop diversification on technical efficiency and not on cost efficiency. The effect crop diversification has on cost efficiency is an interesting area for future studies.

2.3. Empirical Model

A fixed effects ordinary least squares (OLS) was used to determine the effect of crop diversification on technical efficiency. As a robustness check, a Tobit model was also specified. The results of the Tobit model presented in Appendix A Table A1 are very similar to those of the OLS model suggesting little to no effect of possible censoring of efficiency scores on the results. The variables used to calculate efficiency were output of each of the crops listed in appendix A1, and their inputs which included land area, fertilizer and quantity of improved seed. These are the most commonly used key variables used in agricultural production frontiers in developing countries [45]. To estimate the effect of crop diversification on technical efficiency, the following model was estimated:

$$TE_i = \alpha_{0i} + \alpha_{1i}SID + \alpha_{ji}'Z + e_i \quad (10)$$

where TE denotes technical efficiency scores, Z is a vector of farm household characteristics such as age, education, household size, gender and off-farm income as well as production characteristics which included value of agricultural assets, obtaining a loan, livestock ownership, use of soil management techniques, access to technical information, use of fertilizer, use of improved seed and land area cultivated. Our coefficient of interest is α_{1i} .

With regard to the effect of crop diversification on income variability, we adopt a two-step procedure used by [23]. The first step involves computing the income variance for each farmer and the second step involves regressing the calculated variance on explanatory variables using an OLS model. The second-step regression is a fixed effects model which is specified as follows

$$CV_i = \beta_{0i} + \beta_{1i}SID + \beta_{ji}'Z + e_i \quad (11)$$

where all terms in Equation (11) are as defined before. We also estimate a semi-log model as shown in Equation (12) to check if the results are robust to functional form.

$$\log CV_i = \beta_{0i} + \beta_{1i}SID + \beta_{ji}'Z + \varepsilon_i \quad (12)$$

where all variables are as defined before, while ε_i is the stochastic disturbance term assumed to follow a Gaussian distribution with mean zero and constant variance. The coefficient of interest in Equation (12) is β_{1i} .

3. Results

Our results indicate that the average crop diversification index among rural farmers in Zambia is 0.49. Figure 2 shows kernel plots for crop diversification as measured by the SID index and technical efficiency assuming constant returns to scale (CRTS), variable returns to scale (VRTS) and non-increasing returns to scale (NRTS). The figure also shows a kernel plot for the coefficient of crop income variation. These plots suggest that crop diversification and technical efficiency have a negative relationship.

Figure 2. Simpson's index: technical efficiency and coefficient of variation of income of rural farmers in Zambia.

The empirical results are presented in Table 2. The results in Table 2 are consistent with those reported in Figure 2 above. We find that crop diversification has a negative significant impact on technical efficiency at the 5% significance level under the assumption of variable or non-increasing returns to scale production technology (Columns 2 and 3, respectively). We also find similar results at the 10% significance level when we assume constant returns to scale production technology (Column 1). The results show that a one-unit increase in the crop diversification index decreases technical efficiency by between 4.7% and 6.8% depending on the returns to scale.

Table 2. Empirical results on the effect of crop diversification on technical efficiency.

Variables	CRTS Technical Efficiency	VRTS Technical Efficiency	NRTS Technical Efficiency
Age	0.002 (0.002)	0.001 (0.002)	0.001 (0.002)
Age squared	−0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
Female	−0.008 (0.013)	0.004 (0.014)	0.005 (0.014)
Education	−0.001 (0.001)	−0.002 (0.001)	−0.002 (0.001)
Household size	0.001 (0.002)	−0.001 (0.002)	−0.000 (0.002)
SID	−0.047 * (0.027)	−0.068 ** (0.029)	−0.067 ** (0.030)
Agricultural assets	0.000 ** (0.000)	0.000 ** (0.000)	0.000 ** (0.000)
Got loan	−0.006 (0.011)	−0.009 (0.012)	−0.008 (0.012)
Livestock	0.004 (0.004)	0.002 (0.004)	0.001 (0.004)
Off-farm income	0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
Soil management	0.005 ** (0.002)	0.008 *** (0.002)	0.008 *** (0.003)
Technical information	−0.002 * (0.001)	−0.001 (0.001)	−0.001 (0.001)
Kg fertilizer squared	−0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
Kg improved seed	−0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
Hectares planted	0.000 (0.002)	0.001 (0.003)	0.001 (0.003)
constant	0.215 *** (0.053)	0.594 *** (0.056)	0.587 *** (0.058)
Fixed effects	Yes	Yes	Yes
R ²	0.03	0.03	0.02
N	3625	3625	3625

*, **, ***, Statistical significance at 10%, 5%, and 1% levels. Standard error in parenthesis.

The results also show that the value of agricultural assets has a positive significant but negligible effect on technical efficiency. The results further show that rural farmers who practice more soil management techniques are significantly more technically efficiency than those who adopt fewer or no soil management techniques.

The results of the regression of crop diversification on income variability are presented in Table 3. The results from both the linear and semi-log linear are in Columns 2 and 3, respectively. These results are similar by statistical significance. The results show that a one-unit increase in the crop diversification

index decreases income variability by 0.7%, everything else held fixed. This is consistent with the findings of [46]. Other factors that significantly reduce income variability include obtaining a loan, use of improved seed and cultivating a larger land area. The results show that farmers who got a loan had about 0.3% less crop income variability than those who did not. We also find that, as the quantity of improved seed used increases, income variability significantly decreases. Finally, our results show that, as land area under cultivation increases, income variability decreases. Because we focus on the 2015 agricultural season, the R-squared for our results are low. Though not always, this is common and should not be a concern with cross sectional data [47].

Table 3. Effect of crop diversification on income variability.

Variables	Linear Model	Semi Log Model
Age	−0.011 (0.022)	−0.000 (0.000)
Age squared	0.000 (0.000)	0.000 (0.000)
Female	0.029 (0.132)	0.001 (0.001)
Education	−0.000 (0.014)	−0.000 (0.000)
Household size	0.015 (0.018)	0.000 (0.000)
SID	−0.792 *** (0.285)	−0.007 ** (0.003)
Agricultural assets	0.000 * (0.000)	0.000 * (0.000)
Got loan	−0.270 ** (0.121)	−0.003 ** (0.001)
Livestock	0.102 ** (0.042)	0.001 ** (0.000)
Off-farm income	0.000 (0.000)	0.000 (0.000)
Soil management	−0.015 (0.025)	−0.000 (0.000)
Technical information	0.018 (0.013)	0.000 (0.000)
Kg fertilizer squared	0.000 (0.000)	0.000 (0.000)
Kg improved seed	−0.001 ** (0.000)	−0.000 ** (0.000)
Hectares planted	−0.166 *** (0.026)	−0.002 *** (0.000)
Constant	141.137 *** (0.583)	4.948 *** (0.006)
Fixed effects	Yes	Yes
R ²	0.03	0.03
N	4135	4135

*, **, ***, Statistical significance at 10%, 5%, and 1% levels. Standard errors in parenthesis.

4. Discussion

We found an average crop diversification index score of 0.49 among rural farmers in Zambia. This finding suggests that there is a moderate level of crop diversification among farmers in Zambia. The results show a negative relationship between technical efficiency and crop diversification regardless of the type of returns to scale exhibited by the production systems among farmers. This implies that as farmers in Zambia become more diversified, their technical efficiency significantly reduces. This result corroborates findings by [20,21] who both use non-parametric approaches and find that crop diversification significantly leads to greater technical inefficiencies. Our results could be attributed to

the increased competition for resources among the different crops as increases in crop diversification make it difficult for farmers to efficiently allocate their resources. These results imply that policymakers should consider using a policy mix of strategies to balance the decrease in technical efficiency when promoting crop diversification as a resilience strategy. The results show that the strategies that may improve technical efficiency are soil management techniques such as conservation agriculture practices. This is plausible as other studies conducted in Zambia and other areas (e.g., [9,48–50]) have shown that soil and water management practices significantly improve technical efficiency among agricultural producers.

We also found that crop diversification significantly reduces income variability among rural farmers. This finding therefore supports the evidence that crop diversification could be a useful strategy for reducing crop income variability among rural farmers. Since poverty rates among Zambia's rural population are over 70% [51,52], agricultural policies that promote crop diversification could stabilize rural farmers' limited incomes and therefore prevent more households from falling below the poverty line or falling deeper in the poverty trap. The results show that other factors that significantly reduce income variability include obtaining a loan, use of improved seed and cultivating a larger land area. The results suggest that farmers who got a loan had 0.27 less crop income variability than those who did not. This suggests that credit access is another potential strategy for stabilizing farm income. In the years in which yields are low, farmers can borrow some additional funds to meet their consumption and production needs. By providing farmers with an alternative source of financing, access to credit enhances the capacity of farming households to respond promptly and effectively to income shocks, thereby increasing their risk-coping ability.

Moreover, the finding that larger quantities of improved seeds significantly reduce income variability is also plausible. Improved seeds have been found to increase household income, expenditure, food security, and to reduce poverty in developing countries [33–45,53,54]. We partly attribute this finding to the resilience to droughts or diseases for which improved seeds are usually bred for. The use of improved seeds is therefore one of the ex-ante risk management strategies that farm households can use to reduce the sensitivity of farm incomes to potential future shocks. Finally, the finding that an increase in land area allocated to farming or cultivation significantly reduces income variability suggests that larger farms are able to absorb or mitigate income shocks better than smaller farmers. Compared to smaller ones, larger farms may have the capacity and incentive to adopt new and improved production technologies necessary for increasing and stabilizing incomes. That is, the large size of the potential loss faced by large farms may cause them to more actively seek risk-reducing behaviors such as purchasing insurance, adopting improved production methods and equipment, etc.

5. Conclusions

Using nationally representative rural household survey data from Zambia, this study determined the effect of crop diversification on technical efficiency and crop income variability of farm households in Zambia. A better understanding of the effect of crop diversification on farm efficiency and income variability is important for policy initiatives aimed at promoting crop diversification as a climate-smart agricultural strategy for farmers in developing countries.

Our results provide strong evidence that crop diversification involves a trade-off between technical efficiency and income stability. That is, while crop diversification significantly improves income stability, it also significantly reduces technical efficiency. This finding implies that promoting crop diversification as an independent strategy for improving resilience may produce undesirable side effects of reduced technical efficiency. Instead, crop diversification may be better promoted in combination with other technical efficiency-enhancing strategies such as soil and water management techniques. These technical efficiency-enhancing strategies can help to offset or reduce the negative effect of crop diversification on technical efficiency. The results also suggest that, to enhance the resilience of farming households, policy makers can promote strategies that encourage farmers to adopt the use of improved

seeds and to increase their acreage under cultivation. Resilience-enhancing policies can also aim at improving access to credit for farmers.

There are some limitations associated with this study. First, our dataset does not have any information on input prices that could be used to measure cost/economic efficiency. Input prices could help in establishing the role of crop diversification on cost efficiency. Further research can use input prices to shed light on the effect of crop diversification on cost efficiency. Secondly, this analysis could be improved upon by using several years of panel data to capture the variability of income over more agricultural season. Further research could utilize a long panel data analysis to see if the trade-off between technical efficiency and income stability still holds or disappears over time.

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Appendix A

List of crops included in this analysis

1. Maize
2. Sorghum
3. Rice
4. Millet
5. Sunflower
6. Groundnuts
7. Soy
8. Cotton
9. Irish potato
10. Virginia tobacco
11. Barley tobacco
12. Mixed beans
13. Bambara nuts
14. Cowpeas
15. Velvet beans
16. Sweet potato
17. Popcorn
18. Sugar cane
19. Sesame seed
20. Black sun hemp
21. Red sun hemp

Appendix B

Table A1. Tobit regression results of the effect of crop diversification on technical efficiency.

Variables	CRTS_TE	VRTS_TE	NRTS_TE
Age	0.002 (0.002)	0.001 (0.002)	0.001 (0.002)
Age squared	−0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
Female	−0.008 (0.013)	0.004 (0.013)	0.005 (0.014)
Education	−0.001 (0.001)	−0.002 (0.001)	−0.002 (0.001)
Household size	0.001 (0.002)	−0.001 (0.002)	−0.000 (0.002)
SID	−0.047 * (0.027)	−0.068 ** (0.029)	−0.067 ** (0.030)
Agricultural assets	0.000 ** (0.000)	0.000 ** (0.000)	0.000 ** (0.000)
Got loan	−0.006 (0.011)	−0.009 (0.012)	−0.008 (0.012)
Livestock	0.004 (0.004)	0.002 (0.004)	0.001 (0.004)
Off-farm income	0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
Soil management	0.005 ** (0.002)	0.008 *** (0.002)	0.008 *** (0.003)
Technical information	−0.002 * (0.001)	−0.001 (0.001)	−0.001 (0.001)
Kg fertilizer squared	−0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
Kg improved seed	−0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
Hectares planted	0.000 (0.002)	0.001 (0.003)	0.001 (0.003)
Constant	0.215 *** (0.052)	0.594 *** (0.056)	0.587 *** (0.058)
Variance of technical efficiency	0.066 *** (0.002)	0.076 *** (0.002)	0.079 *** (0.002)
Observations	3625	3625	3625

*, **, ***, Statistical significance at 10%, 5%, and 1% levels. Standard error in parenthesis.

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