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Crop Production Diversity and the Well-being of Smallholder Farm Households: Evidence from Nigeria

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ABSTRACT

This paper explores the implications of farmers choosing to diversify their crop production rather than to specialize in one crop on household welfare. Specifically, we estimate the association between household crop production diversity (CD) and household welfare outcomes. To better understand the farmers' production decisions, we also explore the influence that market access and rainfall shocks may have on CD practices. Using fixed-effects models applied to nationally representative panel data for 2010, 2012 and 2015 from the Nigerian Living Standard Measurement Survey, we find that CD is positive and significantly associated with improved household welfare outcomes for households situated father away from markets but the association is not significant for children anthropometric well-being. While a positive association between CD and farm income exist, we find that smallholder households uptake CD due to limited market access, and the exposure to positive and negative rainfall shocks. Our findings contribute to understanding farm household production and consumption behavior and are relevant for policy responses towards reinforcing smallholders' capacity to cope with and adapt to shocks. It can also serve as a guide in prioritizing development efforts to stimulate relevant and well-informed policy and interventions.

Keywords: Crop diversification, climate shocks, market access, household well-being, panel regression, Nigeria.

JEL Classifications: I21, I32, Q13, Q54

EXECUTIVE SUMMARY

Crop diversification (CD) is the growing of more than one crop variety simultaneously on a piece of farm land which is an important livelihood and risk management strategy. It remains an important crop production strategy among smallholder farm households particularly in most Sub Saharan African (SSA) countries, Nigeria inclusive. In Nigeria, many (85%) farming households in Nigeria practice crop diversification, cultivate about 3 crop species and less than 10% of them grow a single crop on the average (LSMS wave 1-3). However, there has been a rising interest among policy experts and development practitioners on how to best design an optimal CD framework to stimulate the welfare of vulnerable households who are often faced with limited market access and largely dependent on rainfed agricultural system for their livelihood.

Besides, the argument in literature on the effect of CD on welfare has been inconclusive as CD has been reported to contribute to healthier diets through greater diversity in household food consumption (Debela et al., 2021; Jones et al., 2014) and also, the linkage between production diversity (CD) and dietary diversity may weaken and even disappear for households with access to food markets (Hirvonen and Hoddinott, 2017). In cases of limited market access, production and consumption decisions may be strongly linked together (Singh, et al., 1986). On the other hand, Jones (2017) argued that the positive association depends on existing levels of CD. This is because households will need to grow at least 9 crops for the association to be significant (Sibhatu and Qaim, 2018). On the contrary, farmers that embrace CD may encounter income losses due to poor production pattern choices and Crop diversity may even "entrench poverty" (Kiani et al., 2021; Appiah-Twumasi and Asale, 2022). Thus, the key question remains whether CD contributes to improved household welfare.

This research answers the following question using Nigeria's Living Standard Measurement Survey national representative data for 2010/2011, 2012/2013 and 2015/2016: What is the relationship between CD and household welfare (measured through household per capita consumption expenditures (PCE), household dietary diversity (HDD), and household food consumptions scores (FCS))? Additionally, we explore the factors influencing CD adoption, and the impact of CD on farm income. Greater insight into how farmers manage and adjust to shocks is important for developing evidence-based policy responses and actions to enhance food and livelihood security. Our estimation strategy follows a two-way fixed effect model to examine the relationship between CD and household welfare and we vary the association in a non-linear manner with market access. We also unpack the factors influencing the uptake of CD among smallholder farm households and its effect on the farm income using Ordinary least square regression and two-way fixed effect panel model respectively.

Generally, we measure crop diversity with crop groups (based on the 7- crop group classification - Cereals, Legumes/pulses, Tubers, Vegetables, Fruits, Tree crops, and Cotton) and crop species (number of varieties of crops planted) and we find that households cultivated two crop groups and just over three crop species on the average between 2010 and 2016. The average number of crop species cultivated rose from 3.1 in 2010 to about 3.3 in 2016. Meanwhile, households growing only one crop group declined from 28% to 25% over this same time period. Household consumption expenditure decreased over the period during the post-harvest season (February to April) but increased in the post planting season (August to October). Likewise, the FCS slightly decreased over the period while there was a slight increase in the HDDS over the period with the household consuming about 6 food groups and having an average FCS of 23 in almost all cases. The post-harvest and post planting variation shows the importance of seasonality in the condition of household welfare while the FCS reveals that most of the households are within the borderline (i.e., between 21-35 based on classification of the World Food Programme (2008) category. Additionally, we observed that the HDDS is higher during post planting than in the post-harvest season. On the contrary, household consumption expenditure and FCS is lower in post planting than in the postharvest season.

Our results reveal that for households with limited access to market, crop-production diversity is positively associated with household welfare, especially with the quality of household diets, though the associations are small. As households that are 64km from the market, growing an extra crop is associated with 0.04 additional food groups consumed by the households on an average. Hence, CD is associated with more diverse diet (HDDS and FCS), and this association is larger the farther households are from markets. The marginal effect (magnitude) of crop diversification at various distances to the market is positive and significantly associated with household well-being, although it appears negatively associated with household per capita consumption expenditure during the post-harvest season. The magnitude of CD at 64km (50%) distance to market is associated with a 4.0%, 0.12 and 1.18 unit increase in PCE, HDDS and FCS during the post planting season while it is associated with a reduction of 5% in PCE but with an increase of 0.04 and 0.33 unit in HDDS and FCS during the post-harvest season respectively.

Additionally, we find that absolute negative rainfall deviation (less rainfall than historical average rainfall) reduces CD significantly while absolute positive rainfall deviation (more rainfall than historical average rainfall) increased CD. Household's distance to a market had a positive and declining association with CD which becomes negative for households situated more than 70km away from the market. Lastly, we find that CD positively influence farm profit; while absolute negative rainfall deviation reduces farm profit and absolute positive rainfall deviation increase farm profit significantly.

An understanding of the pathways through which CD affects household well-being and the factors influencing CD uptake is important for policy making in Nigeria and most sub-Saharan African countries. The simultaneous growing of more than one crop species is an important production strategy commonly employed by majority of smallholder farmers. Although these farmers are responsible for the bulk of food production in the region, they rely on rainfed agriculture which makes them vulnerable to rainfall shocks and be at risk of food insecurity. Therefore, stemming from our research findings, we conclude that there is positive association between CD and quality of household diet especially for households with limited market access; and a higher impact of positive rainfall shocks on CD as compared to negative rainfall shocks. Based on these, we therefore draw the following policy inference:

First, Risk Management: Since our result has shown a mixed association between CD and shocks, promoting CD may be a key option to be promoted amongst farmers especially resource poor farmers when faced with either positive or negative shocks. An understanding of the interaction between CD and shock is also important in designing intervention programmes aimed at stimulating the adaptive capacity of farmers to cope with extreme weather events and garner support from the government through early warning information and inputs. We need stronger evidence of the positive association between CD and farm profit and CD and household consumption levels, as these positive associations suggest that CD can be an effective risk management strategy that does not come at the expense of income generation. Second, Capacity building: There is also a need to enhance the capacity of farmers on the right combination of crops to plant as well as the species counts. Lastly, given the importance of the positive association between CD and farm profit, CD that is market-oriented may likely have a stronger positive effect on household dietary diversity as compared to CD that is more subsistence-oriented. Hence, government and non-governmental organisations should work collectively to improve market access of smallholder households to enable them make rational choices on crop diversification decision for optima gain that may likely occur through specialization.

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ACRONYMS AND ABBREVIATIONS

CD	Crop Diversification
HDDS	Household Dietary Diversity Score
FCS	Food Consumption Score
HAZ	Height for Age Z-score
HAD	Height for Age Difference
LSMS	Living Standard Measurement Survey
OLS	Ordinary Least Square

I. Introduction

Growing more than one crop species at a time is a commonly practiced production strategy observed among smallholder farmers throughout sub-Saharan Africa, particularly in Nigeria (Isbell et al., 2021; Alobo Loison, 2015). Data from the Living Standards Measurement Survey (LSMS) for Nigeria indicate that roughly 85% of smallholder farmers in the country practiced crop production diversification (CD) between 2010 and 2015. CD involves simultaneously cultivating a variety of crop species that suit local conditions, serving as a strategy to mitigate and cope with both socioeconomic and environmental shocks and risks (Labeyrie et al., 2021; Alobo Loison, 2015; Lin, 2011). This approach not only fosters synergies among crops (Di Falco et al., 2010), it also lowers the risk of pest and disease outbreaks caused by climate variability (Chakraborty and Newton, 2011; Lin, 2011). Furthermore, it reduces the vulnerability to complete crop failure associated with relying solely on one crop species (Bellon et al., 2020; Renard and Tilman, 2019; Makate et al., 2016).

Aside from diversifying risk, CD can also contribute to healthier diets through greater diversity in household food consumption, particularly for women and children, especially in settings where most food is produced for home consumption (Debela et al., 2021; Murendo et al., 2018; Adjimoti and Kwadzo, 2018; Jones et al., 2014). Evidence suggests that CD may enhance household food consumption scores by increasing both the quantity (calories) and variety of food that households consume (Mango et al., 2018), thereby enhancing food security (Appiah-Twumasi and Asale, 2022). However, the link between production diversity (CD) and dietary diversity may weaken and even disappear for households with access to food markets (Hirvonen and Hoddinott, 2017). In such cases, market access allows farming households to separate their production decisions from their consumption decisions by focusing on maximizing farm income and then acquiring healthy diverse diets through food purchases (Khonje et al. 2022; Mulwa and Visser 2020; Sibhatu and Qaim, 2017). Conversely, limited market access may tie household diet quality and diversity to the diversity of crops that households produce for their own consumption, where production and consumption decisions are non-separable (Singh, et al., 1986).

Despite evidence indicating a positive and statistically significant link between CD and the diets and nutrition of smallholder farm households (Sibhatu and Qaim 2018b; Vernooy, 2022), the magnitude of the association tends to be modest and depends on the degree of existing CD (Jones, 2017). In instances where positive associations between CD and the quality of household diets are found, households may need to grow nine additional crops to increase the number of food groups consumed by one (Sibhatu and Qaim, 2018b). Not all of the evidence indicates that households practicing CD are better off. Sibhatu and Qaim (2018a) found that the associations are often insignificant when CD is measured by food group rather than species count. Crop diversity may even “entrench poverty” by limiting household specialization and income earning, even though there may be valid reasons for pursuing CD (Appiah-Twumasi and Asale, 2022). Furthermore, farmers embracing CD may encounter income losses due to poor production pattern choices (Kiani et al., 2021). Thus, it is unclear whether CD contributes to improved household welfare.

While differences in smallholder market access and participation may influence the degree to which CD and household diet quality are linked (Sibhatu et al., 2015), most smallholder farmers nonetheless consume a large portion of what they produce. Thus, there is a need to identify approaches to make smallholder agriculture sustainable and more nutrition-sensitive (Qaim, 2017; Sibhatu and Qaim, 2017; Frelat et al., 2016; Chamberlin et al., 2014; Ruel and Alderman, 2013). However, empirical findings remain mixed and context-specific (Sibhatu and Qaim, 2018; Fanzo, 2017; Powell et al., 2017; Sibhatu et al., 2015), underscoring the importance of understanding the pathways through which CD can enhance the quality of household diets overall welfare. This paper therefore studies the relationship between CD and household welfare. In particular, we use two-way fixed effects models to estimate the association between CD and (a) household per capita consumption expenditures (PCE), (b) household dietary diversity (HDD), (c) household food consumptions scores (FCS), and (d) children's nutrition outcomes. Additionally, we explore the factors influencing the adoption of CD, and how CD may impact farm profit. We account for the potential non-separability of household production and consumption decisions by allowing the relationship between CD and household welfare to vary by degree of market access. We empirically estimate these relationships using nationally representative data from Nigeria spanning a period of six years (2010-2015).

We find that there is no significant correspondence between CD and welfare outcomes in the post planting (August to October) data collection across survey waves. In the postharvest (February to April), CD is positively associated with higher per capita expenditures but there is no significant association with household diet diversity. Similarly, CD also does not correspond with improved child anthropometry outcomes. (HAZ and HAD). But with limited market access, CD becomes positively associated with improve household welfare especially the quality of household diet across both season, while CD appears to be negative and significantly associated with PCE during the post-harvest season. A reduced form estimation of factors that could explain adoption of CD shows a positive association when households experienced more rainfall in the previous planting season than in the long term annual averages. Households within the 50th percentile of distance to a market are more likely to practice CD. As distance increases there is lower likelihood of CD adoption. Households within the 50th and 75th percentiles of distance to a market have higher farm profit than households closest to the market. Generally, our result is consistent with our robustness checks with the exception that the magnitudes when species count is used appears bigger. This aligns with the past findings that CD can be significantly associated with increased household welfare only when market access is constrained (Hirvonen and Hoddinott, 2017; Sibhatu and Qaim, 2017; Jones, 2017).

Our paper contributes in several key ways. First, we use various household outcomes (PCE, HDD and FCS) as well as child nutrition outcomes (anthropometric measures of stature for age) as measures of welfare. Second, the time series analysis allows to control for unobserved farm level heterogeneity that would affect both uptake of CD and household welfare outcomes, thus providing better estimates compared to previous studies (Baiyegunhi et al., 2022; Appiah-Twumasi and Asale, 2022; Douyon et al., 2022; Sibhatu and Qaim, 2018a; Mango et al., 2018; Adjimoti and Kwadzo, 2018; Hirvonen and Hoddinott, 2017) that used cross sectional data. Third, we focus on using categories of crop groups to conceptualize CD rather than using species which may not differ substantially from previous studies (Khonje et al., 2022; Sibhatu and Qaim, 2018b; Sibhatu and Qaim; 2017). Our models also benefit from the inclusion of a wide range of control variables, encompassing individual and household socioeconomic characteristics, institutional factors, and locational factors, thus enhancing the robustness of our estimates.

The rest of the paper is structured as follows; section 2 presents the conceptual framework; section 3 provides a description of the data, section 4 outlines the econometric methodology adopted for the study, section 5 presents the results, and section 6 concludes with a discussion of the results.

II. Conceptual Framework

Economic theory predicts that in a perfect market, production and food decisions of agricultural households are separable and they are non-separable in an imperfect market. It is likely that in most rural households in developing countries, production and foods decisions are non-separable. Indeed, many household production decisions are not solely driven by profits but by other household decisions such as consumption, health and education amongst others. In the mean-variance portfolio optimization model developed by Keenan, Karanja, Pamuk & Ruben (2022), both consumption and production choices are non-separable. They assume that farming households are able to produce multiple crops with fixed amount of labor and land. These households can consume and sell from their own food production, as well as purchase food items at exogenous market prices.

The choice to diversify production by a typical household is subject to several reasons. A farmer may diversify production to cope from the risks associated with climate or economic shocks. These shocks may stem from incidences such as droughts, floods, death of household heads or members contributing financially to the households, and/or increase in the price of inputs amongst others. Ex-ante risk management strategies (crop diversification inclusive) adopted by farmers are usually different from the ex-post coping mechanisms such as consumption and asset smoothening for short time survival plan (Angelsen & Dokken, 2018). With good rainfall, households may shift from being net sellers to net buyers during years with poor rainfall. This paper is centered on understanding the influence of market access and shocks on crop diversification and its resultant effect on household welfare.

This study tests the following hypotheses: First, we hypothesize that positive correlation exists between crop diversification and household welfare with an increase in distance from market. Secondly, we hypothesize that negative shocks are positively correlated with crop diversification. Therefore, previous exposure to shocks will increase the likelihood of crop diversification by a household in the future. Households that are exposed to extreme weather variability may likely diversify their production to recover from shock. Farmers that experience drought tend to adopt drought resistant varieties and in the case of late or heavy rainfalls, early maturing varieties and crop diversification as the case may be. Third, we hypothesize that distance to market is positively correlated with crop diversification. As we earlier stated, limited access to market is usually associated with increased crop diversification to cover the crops that they are unable to purchase due to market distance. Fourth, we hypothesize that crop diversification is negatively correlated with farm profit. Crop diversification negates the assumption of gains from specialization, there is a likelihood that farm profit will reduce with increase in crop diversification.

Thus, if household consumption and production decisions are not separable (i.e., market access is limited), then production diversity may be necessary for more nutritious diets. However, when households have unlimited access to markets, they can earn income from whatever farming practices that are most profitable and acquire a diverse diet through purchases from the market (Hirvonen and Hoddinott, 2017). Sibhatu and Qaim (2017) argued that both farm and off farm income are important in food security even though income from sales of agricultural products are often affected by seasonality, while off farm income can be used to flatten this effect. Additionally, they argued that market access is more important than subsistence farm production in dietary diversity at every period of the year but this is otherwise for calorie dense-staple foods like cereals than other highly perishable food groups.

Appiah-Twumasi and Asale (2022) found that crop diversification alongside access to extension services and the use of soil fertility management practices increased the food access dimension of the food security of households in Northern Ghana. In addition, the vulnerability of smallholder farm households to climate change, economic shocks and uncertainties can be the key drivers of CD decisions (Frelat et al., 2016), and this decision can help in building resilience to climate change (Kiani et al., 2021). Also, Crop diversification can increase and stabilize productivity, increase profit margin, and consequently, improve household welfare (Fung et al., 2019; Bedoussac et al., 2015; Matusso et al., 2014). Khonje et al. (2018) found that the joint adoption of multiple agricultural technologies had better impact on yields, household incomes, and poverty. Because of the likely complementarity effect when the right combination of modern technologies is used or crop species are grown together, farmers may experience increased productivity, farm profit and other welfare outcomes increase.

Farmers who adopt crop diversification in combination (with the adoption of early maturing maize variety) or in isolation (without the adoption of early maturing maize variety) realized increased maize productivity and net farm income per hectare, but the adoption of modern technology had the highest welfare outcomes (Baiyegunhi et al., 2022). While the primary determinants of agricultural diversification include demographic and institutional factors and not the social factors (Kiani et al., 2021). Douyon et al. (2022), highlighted that access to technologies promote food diversification and improve food and nutritional security, especially in rural areas as the socioeconomic factors had a positive influence on crop diversification.

III. Data Description

This study uses waves 1 (2010/2011), 2 (2012/2013) and 3 (2015/2016) of the Nigerian Living Standard Measurement Survey (LSMS) collected by the World Bank and Nigeria National Bureau of Statistics. The Living Standard Measurement Survey data is a national representative household survey. The data collection was conducted twice for each wave: the first-round between August and October, and the second round between February and April. The data also have geographic identifiers for each household which help us to control for the effect of the geographic location in our analysis. The household questionnaire covers household characteristics, food and non-food consumption expenditures, and food security using seven days' recall. We selected the first 3 waves because the same households were repeatedly visited during these periods as compared to Wave 4, where there was a replacement of about 1500 households.

In constructing the variable for rainfall shock, we use the unique household location coordinates from the LSMS data and downloaded precipitation data from ERA 5 within a 21km radius for the period 1979 to 2014. Using the average calendar of rainfall patterns in Nigeria (i.e., March to October in the South and Late April to September in the North), we calculated the historical (1979 – 2008 for wave 1, 1979 – 2010 for wave 2, and 1979 – 2013 for wave 3) and current averages (i.e., survey period t-1) of precipitation in rainfall months (mm) for the Northern and Southern regions in Nigeria. We use the difference between historical and current precipitation based on rainfall patterns by zone following Makate et al. (2022, 2023) given that the current planting decisions by smallholder farm households will be likely based on their experience in the previous year (Huang et al., 2014). In addition to our key variable of interests (market access and shocks), we include several household characteristics and location variables to understand crop diversification choices across households and geopolitical zones.

For our farm profit, we focus on crop farm profit using the survey weight. We multiplied the median prices (i.e., in real value with reference year) of all crop commodities at state, zone, and country level with the quantity of crops harvested/ expected to be harvested. The summation of the value of crops harvested minus the total cost of inputs used by households for the crop production activities gives us the variable farm profit as used in our model.

Measuring Crop Diversity

The most frequently used measure of crop diversity on a farm is the species count (Sibhatu et al., 2015). For this study, we use two measures of crop diversity. We use a 7-crop group classification (Cereals, Legumes/pulses, Tubers, Vegetable, Fruits, Tree crop, and Cotton) and species counts (continuous) as a measure of crop diversity.

Measuring the Welfare Outcomes

We measure welfare outcomes using: household per capita real consumption expenditure, food consumption score, household dietary diversity score (HDD), height for age Z score (HAZ) and height for age difference (HAD) using data of children between 0 - 59 months (WHO, 2008). The World Bank consumer price index for 2010 was used as our base year to generate the real values of the household per capita consumption expenditure. We construct the food consumption score (FCS) based on the guideline of the World Food Program (2008) by first summing the frequencies of consumption of food items in each group, then multiplying by the value of each food group's weight (main staples - 2, pulses - 3, vegetables - 1, fruit - 1, meat/fish - 4, milk – 4, sugar - 0.5, and oil - 0.5) and adding the weighted food group scores to get the FCS.

Summary Statistics for the Household Variables

Table 1 presents the summary statistics for smallholder household welfare with their socioeconomic, farm and institutional characteristics using the survey weight for the three periods (2010/2011, 2012/2013 and 2015/2016). Generally, households cultivate three crop species and two crop groups on the average across the periods as there is a slight increase in the number of crop species and crop groups cultivated by the household over the period. For instance, the average number of crop species rose from 3.1 in 2010 to about 3.3 in 2015. However, 28.4%, 23.1% and 24.6% of the households only planted a single crop group during wave 1, wave 2 and wave 3 respectively. All welfare outcomes of households that planted a single crop group is lower when compared with those that planted multiple crop groups. See Table 7 in the appendix.

Household consumption expenditure decreased over the period during the post-harvest season but increased in the post planting season. Likewise, the FCS slightly decreased over the period while there was a slight increase in the HDD over the period with the household consuming about 6 food groups and having an average FCS of 23 in almost all cases. The post-harvest and post planting variation shows the importance of seasonality in the condition of household welfare while the FCS reveals that most of the households are within the borderline (i.e., based on classification of the World Food Programme 2008). Additionally, we observed that the HDD is higher during post planting than in the post-harvest season. On the contrary, household consumption expenditure and FCS is lower in post planting than in the postharvest season. This slightly contradicts our a priori expectation that households will fare better during the post-harvest than the post planting season. The result for the mean distribution of household welfare outcome across the three waves for households who planted one crop group is presented in Table 7 in the appendix.

Child welfare (HAZ and HAD) from the surveyed households improves greatly with values increasing from -1.6 and -6.2 in 2010 to -0.75 and -2.8 in 2012 respectively. Although they worsen in 2015, they are still better as compared to that of 2010. However, it may be due to poor harvest as they might have experienced negative shock(s) in the forms of prolonged drought during production. It is unsurprising that farm profits also decline over the two periods which may also be due to negative shocks in the form of poor harvest, and high input cost among others.

Table 1: Summary statistics

	2010/2011		2012/2013		2015/2016	
	(N=2,606 HH)		(N=2,659 HH)		(N=2,615 HH)	
	Mean	std. dev.	mean	std. dev.	mean	std. dev.
Crop diversification measurement						
Crop groups (7 groups)	1.98	.81	2.08	.78	2.03	.78
Percent growing one crop group	28.4	-	23.1	-	24.6	-
Outcome variable						
Post-harvest						
Total consumption expenditure (₦) **	73,209	59,250	65,165	131,243	62,532	71,518
HDD (7 food groups)	5.80	1.01	5.94	.93	6.07	.84
Food consumption score	24.51	9.00	23.19	9.22	24.08	8.97
Post-planting						
Total consumption expenditure (₦) **	59,493	42,238	67,581	117,540	62,888	84,911
HDD (7 food groups)	5.70	1.15	5.66	1.13	6.08	.86
Food consumption score	25.17	11.06	22.82	9.38	24.86	10.37
Child nutrition outcomes - HAZ	-1.63	1.93	-.75	1.67	-1.35	2.08
HAD	-6.20	7.17	-2.84	5.83	-4.61	7.28
Farm profit (₦) **	77,886	78,682	77,990	78,580	68,419	79,526
Control variables						
Absolute standardized rainfall (R) (mm)	.81	.61	.83	.59	.86	.57
Positive rainfall (PR) (*)	.45	.50	.38	.49	.27	.44
Distance to market (KM)	69.77	38.99	67.71	38.88	67.53	38.64
Socio-economic Characteristics						
Household head is male (*)	.93	.26	.93	.25	.94	.24
Household head's age	50.42	13.71	51.75	13.72	52.59	13.10
Household head's years of education	5.74	5.68	5.54	5.68	5.88	5.93
Household size	7.61	3.21	7.90	3.26	7.87	3.17
Farm size (ha)	.86	.98	.84	.91	.93	.97
Value of productive assets owned (₦)	104,089	478,105	66,204	130,799	59,522	256,297
Farm Characteristics						
Pesticide use (*)	.15	.36	.16	.37	.23	.42
Herbicides use (*)	.20	.40	.22	.41	.30	.46
Animal traction use (*)	.21	.41	.27	.44	.16	.37
Fertilizer use (*)	.46	.50	.48	.50	.53	.50
Soil nutrient available moderate (*)	.37	.48	.37	.48	.39	.49
Soil nutrient available severe (*)	.24	.43	.22	.41	.20	.40
Soil nutrient retention (*)	.32	.47	.35	.48	.34	.47
Soil root condition (*)	.19	.39	.19	.40	.19	.39

Note: (*) indicates a binary (0/1) variable. HH refers to household. Figure in parenthesis are percentages of household where crop group or species count equal 1, ** Values in real terms with 2010 as the base year from the World Bank Consumer Price Index data; pesticides, herbicides and fertilizer use indicate farm households that use any type of these input on any of their farm plots, animal traction use indicates households that use animals for ploughing on any of their fam plots. The sample size for the children anthropometric well-being across the three survey waves is as follows 2010 (N=1008 Child); 2012 (N=1731 Child); and 2015 (N=1879 Child).
Source: Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.

The absolute standardized weather deviation from long term mean (precipitation) increased over the survey periods from 0.81mm, in 2010 to 0.83mm in 2012 and later increased to 0.86mm in 2015. Likewise, household distance to the nearest market declined over the three periods which suggests a slight improvement in the households' access to market as the average distance falls from 69.8km in 2010 to about 67.5km in 2015.

Figures 1-3 shows the parametric linear regression between CD and household welfare. The result suggests a positive association between CD and household welfare (i.e., household per capita expenditure, HDD and FCS). The 95% confidence interval around the fitted line appears wide and show greater uncertainty in the fitted line for the CD and log of household per capita expenditure, while it appears narrow for CD association with HDD and FCS which indicates more precision of the fitted regression line. As the confidence interval does not include zero, it implies that the relationship between CD and household welfare is statistically significant.

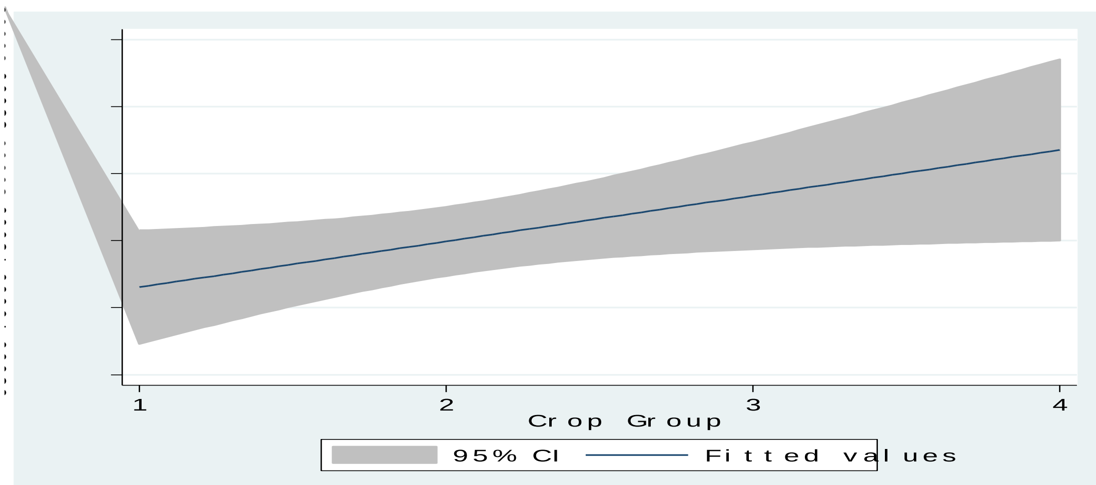

Figure 1: Per capita expenditure vs Crop Group

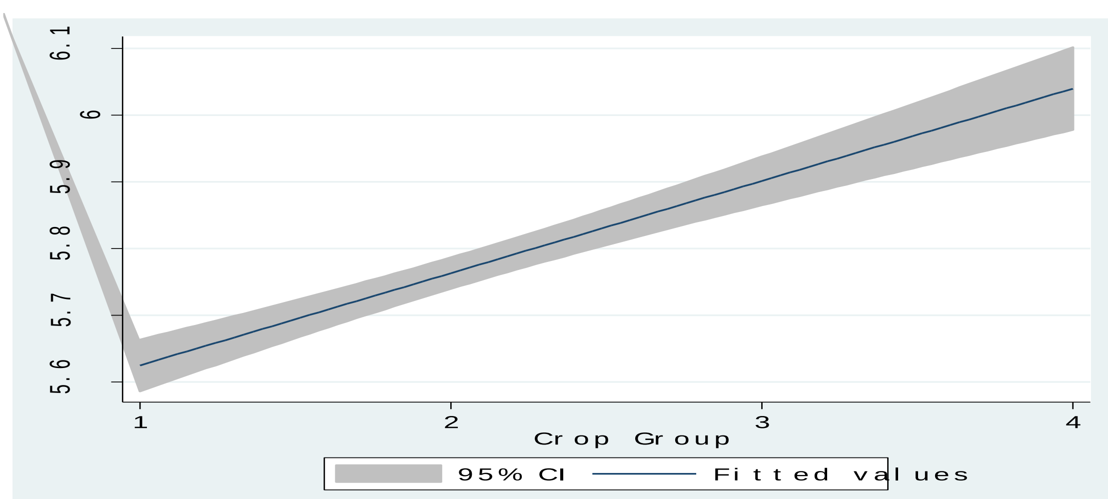

Figure 2: HDD vs Crop Group

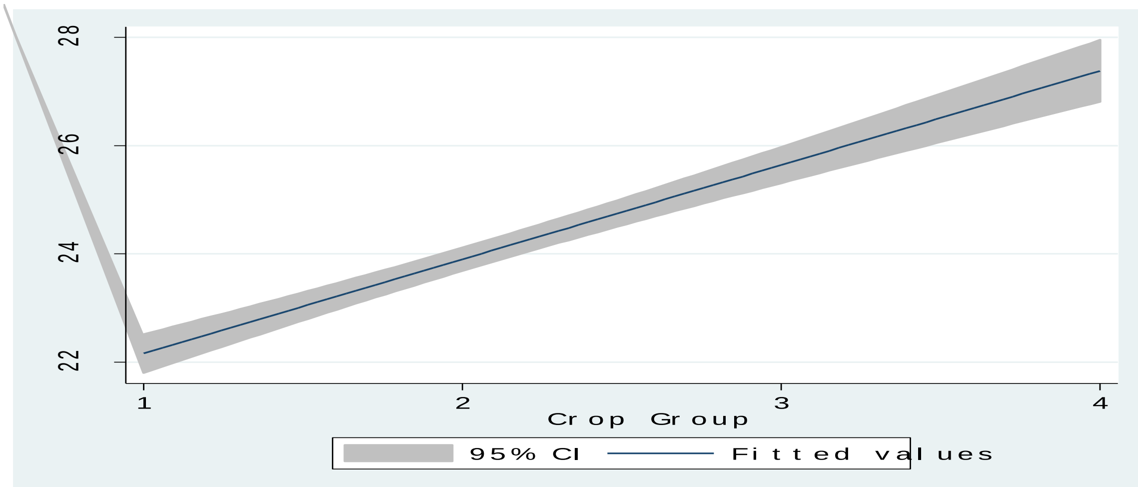

Figure 3: FCS vs Crop Group

Note: Figure 1- 3 are parametric linear regression. Shaded area refers to 95%-confidence interval.
Source: Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.

IV. Econometric Approach

In this study, we consider three models related to CD. First, we estimate the association between household and child welfare and CD practices, allowing for the relationship to vary with access to markets. Second, we explore the decisions of farmers to choose CD strategies by estimating the relationship between CD and households' exposure to shocks and access to markets. Third, we estimate the relationship between farm profit and CD to better understand the mechanisms that relate CD to household welfare.

To estimate the association between CD and household welfare, we specify the following two-way fixed effects model for both the post-planting and post-harvest samples:

$$W_{ht} = \gamma_0 + \gamma_1 CD_{ht} + \gamma_2 D_{ht} + \gamma_3 D_{ht}^2 + \gamma_4 (CD_{ht} * D_{ht}) + \gamma_5 (CD_{ht} * D_{ht}^2) + \gamma_6 X_{ht} + \lambda_t + \mu_h + \upsilon_{ht} , \quad (1)$$

where W_{ht} is the welfare outcome (PCE, HDD, FCS) for household *h* and time *t*, and CD_{ht} is the number of crop groups cultivated by household *h* during time *t*. To allow the relationship between CD and household welfare to vary in a non-linear manner with market access, we include the distance from the household to the nearest market (D_{ht}) entered as a quadratic (D_{ht}^2), and interact this quadratic relationship with CD ($CD_{ht} * D_{ht}$ and $CD_{ht} * D_{ht}^2$). Thus, the marginal effect of CD on household welfare depends on the distance to the market (market access):

$$ME = \frac{\partial W}{\partial CD} = \gamma_1 + \gamma_4 D + \gamma_5 D^2$$

Given this relationship, we see that if production and consumption decisions are indeed separable for households located in the market town (i.e. $D = 0$), and hence the quality of household diets (W) is de-linked from CD, we would expect the marginal effect at in the market town to be zero (i.e. $\gamma_1 = 0$). If households that are farther from the market must rely on the diversity of the crops that they produce to acquire diverse and high-quality diets (i.e. household production and consumption decisions are non-separable), then we expect the marginal effect to be positive. To test this, we evaluate the marginal effect at the 25th, 50th and 75th percentiles of the distance to markets in the sample (i.e. 43, 64, and 93 km, respectively) and report these results in Table 2.

To reduce the bias of the estimators for the γ_s of interest (i.e. γ_1, γ_4, and γ_5), we include the set of control variables (X_{ht}) listed in Table 1. Further, we include a household fixed effect (μ_h) to account for household time-invariant unobservables, and a time fixed effect (λ_t) to account for economy-wide time trends, both of which might co-determine CD and household welfare and hence bias our marginal effect estimates. υ_{ht} is an idiosyncratic error term.

The two-way fixed effects model in equation (1) was also used to estimate the marginal effects of CD on child nutrition outcomes (HAZ and HAD). These estimates are reported in Table 3. Although the two-way fixed-effects specification addresses endogeneity due to time-invariant unobservables, it does not address the issue of reverse causality where household PCE, HDD, FCS or children's nutrition outcomes may affect the households' CD decisions. We therefore remain cautious in our interpretation of the estimated relationship between welfare outcomes and CD, and do not assert causality.

To estimate the factors that affect farming households' CD decisions, we specify the following model:

$$CD_{ht} = \beta_0 + \beta_1 R_{ht-1} + \beta_2 PR_{ht-1} + \beta_3 (R_{ht-1} * PR_{ht-1}) + \beta_4 D_{ht} + \beta_5 D_{ht}^2 + \beta_6 X_{ht} + \lambda_t + \xi_{ht} \quad (2)$$

To test whether rainfall shocks affect the number of crop groups that farmers cultivate, we include in the model the absolute value of the deviation of rainfall in the previous year from long term average, along with a dummy variable indicating whether the rainfall deviation was above average (i.e. positive; PR_{ht-1}), and an interaction of these two variables. The marginal effect of rainfall shocks on CD thus depends on whether the shock is negative (β_1) or positive ($\beta_1 + \beta_3$):

$$ME = \frac{\partial CD}{\partial R} = \beta_1 + \beta_3 PR$$

To test whether market access affects the CD strategies of farming households in a nonlinear manner, we include distance from the household to the nearest market (D_{ht}) entered as a quadratic (D_{ht}^2). The marginal effect of market access on CD thus on how far households are from the market:

$$ME = \frac{\partial CD}{\partial D} = \beta_4 + 2\beta_5 D$$

As with model (1), we test this by evaluating the marginal effect at the 25th, 50th and 75th percentiles of the distance to markets in the sample (i.e. 43, 64, and 95 km, respectively). These results are reported these results in Table 4.

Control variables (X_{ht}) and a time fixed effect (λ_t) are also included to reduce omitted variable bias. We do not include individual fixed effects in this model as there is little within-household variation in distance to nearest market over time, and we are interested in estimating the relationship between market access and CD. We thus estimate model (2) with OLS. While we are reasonably confident that rainfall shocks are exogenous, we are more cautious about market access, and thus do not assert causality in our interpretation of the estimated relationship between market access and CD.

Lastly, to understand the likely pathway(s) through which CD can influence household welfare, we specify a two-way fixed effect model of farm profit (FI_{ht}) as a function of CD:

$$FI_{ht} = \alpha_0 + \alpha_1 CD_{ht} + \alpha_2 R_{ht-1} + \alpha_3 PR_{ht-1} + \alpha_4 (R_{ht-1} * PR_{ht-1}) + \alpha_5 D_{ht} + \alpha_6 D_{ht}^2 + \alpha_7 X_{ht} + \lambda_t + \mu_h + \varepsilon_{ht} \text{ , (3)}$$

The parameter of interest in this model is α_1, the association between household CD practices and farm profit. These results are reported in Table 5.

V. Results

Association Between Household Welfare Outcomes and Crop Diversity

This section presents our finding on the association between CD and household welfare (Equations 1 and 2) for both the post planting and postharvest seasons. Table 2 shows the result of the fixed effect model estimates of the association between CD and household welfare outcomes (per capita expenditure, HDD, and FCS). We observed that CD (crop groups planted), distance to market, the interaction between CD and distance had no significant effect on welfare outcomes measured using PCE, HDD, FCS during the post planting and postharvest season.

The result reveals that there is a positive and significant association between CD and log of per capita expenditure during the postharvest season. As 1 unit change in the level of CD is associated with 10.9% increase in PCE. While there is insignificant positive association between CD and HDD and FCS when households are located at the markets during the post-planting and postharvest seasons. We expect that the further a household is located from the market, the higher the likelihood of diversifying crop production. This is because of the existence of a price wedge brought about by the addition of the transaction cost incurred as a result of a farther market distance and the difference between the selling and buying price.

Unexpectedly, there is no significant association between distance to market, its square or its interaction with CD and the household welfare outcomes with the exception of the log of per capita expenditure during the postharvest round. Similar results were obtained in the interaction between crop groups and distance to market as well as in the interaction between crop group and square of distance to market and log of per capita expenditure. However, our estimation of the marginal effect of CD at various distances (25th, 50th and 75th percentile) to the market shows that CD becomes significantly associated with improved household welfare when there is limited market access. This marginal effect depends on how far smallholder households are from the market and this relationship may be nonlinear. For instance, the marginal effect of CD at 64km (50th percentile) distance to market is associated with 0.04 0.12 and 1.18 unit increase in PCE, HDD and FCS during the post planting season respectively. While it is associated with a 0.05 unit reduction in PCE but associated with an increase of 0.04 and 0.33 unit in HDD and FCS during the post-harvest season.

Also, the magnitudes of the marginal effect of CD at various market distance is different across the welfare outcomes as it appears bigger during post planting than the postharvest season. The observed negative and significant marginal effect of CD at 64km and 95km market on log of per capita expenditure is not surprising. As the farther a household is located from the market, the higher the likelihood of diversifying crop production. This is because a price wedge may likely occur due to the addition of the transaction cost incurred arising from the market distance coupled with the differences between the selling and buying prices.

Table 2: Correlates of Household Welfare Outcomes (Log of PCE, HDDS and FCS)

Two-Way Fixed Effects Model

	Post planting			Post harvest		
	lnPCE	**HDD**	**FCS**	**lnPCE**	**HDD**	**FCS**
Crop diversity (*CD*)	.012	.075	.816	.109***	.099	.227
	(.043)	(.077)	(.682)	(.041)	(.068)	(.652)
Distance to market (*D*)	.001	-.008	-.033	.010	015	.063
	(.008)	(.020)	(.110)	(.007)	(.025)	(.164)
Distance to market squared (D^2)	-.000	.000	.000	-.000*	-.000	-.001
	(.000)	(.000)	(.001)	(.000)	(.000)	(.001)
*CD*D*	.000	.001	.008	-.004***	-.002	-.001
	(.001)	(0.02)	(.018)	(.001)	(.002)	(.017)
$CD*D^2$	-.000	-.000	-.000	.000***	.000	.000
	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
Marginal effect of CD						
- evaluated at 43km from market	.030**	.112***	1.087***	-.020	.047**	.263
- evaluated at 64km from market	.037***	.120***	1.180***	-.045***	.037*	.328*
- evaluated at 95km from market	0.46***	.120***	1.273***	-.038**	.043	.484**
Control	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	7,481	7,467	7,467	7,480	7,475	7,475
F	24.55	13.65	9.32	24.05	4.35	2.34
Prob >F	0.00	0.00	0.00	0.00	0.00	0.00
Mean HH welfare outcome CD=1	74,530	5.63	22.90	82,136	5.81	23.27

Note: Robust standard errors in parentheses. Statistical significance denoted at ***p < 0.01, **p < 0.05, *p < 0.1. Natural log of per capita expenditure, Household Dietary Diversity, and Food Consumption Score are denoted as lnPCE, HDD and FCS, respectively.

Source: Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.

Association Between Crop Diversity and Child Nutrition Outcomes

Table 3 shows the estimates of the regression for the association between CD and household welfare equation (Eq. 1 and 2) when the latter is proxy by child height-for-age Z-scores (HAZ) and child height-for-age differences (HAD). Following the same systematic approach, the estimates of a quadratic function are provided in models 1 for HAD and HAZ respectively, as well as the estimates of the model with the inclusion of all the control variables (models 2). The coefficient of CD appears negative and insignificant for child's wellbeing of smallholder farm household in almost all cases with the exception of the quadratic function without the control variables under HAZ with a negative significant coefficient ($p < 0.1$).

The coefficient of the distance to market appears negative and insignificant for all the models. This suggests that there may be little or no association between child wellbeing of the smallholder farmers as other factors might be more important than the market access. The marginal effect estimated at different market distance interval is negative and insignificant in all cases. This suggest that the marginal effect of CD on HAZ is insignificant irrespective of how far the household is located away from the market. This may due to the fact that it takes longer time to observe the marginal effect of CD at various distance to market on the child anthropometric well-being.

Table 3: Correlates of Child Nutrition Outcomes (Height-for-Age Z-Scores and Differences)

Two-Way Fixed Effects Models

	HAZ	HAD
Crop diversity (*CD*)	-.233	-.816
	(.255)	(.892)
Distance to market (*D*)	-.004	-.099
	(.056)	(.188)
Distance to market squared (D^2)	-.000	.001
	(.000)	(.001)
*CD*D*	.003	.010
	(.008)	(.028)
CDD^2	-.000	-.000
	(.000)	(.000)
Marginal effect of *CD*		
- evaluated at 43km from market	-.110	-.380
- evaluated at 64km from market	-.050	-.159
- evaluated at 95km from market	.040	-.179
Controls	Yes	Yes
Number of observations	4,462	4,462
F	1.52	1.47
Prob > F	0.05	0.07
Mean of Child Nutrition Outcome for CD=1	-1.20	-4.34

Note: robust standard errors in parentheses. Statistical significance denoted at ***p < 0.01, **p < 0.05, *p < 0.1. CD measured by Crop group and Distance to market in KMs. **Source:** Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.

Association Between Crop Diversity, Rainfall Shocks and Market Access

Table 4 presents the regression result using ordinary least squares (OLS) to estimate the factors influencing smallholder farm households' decisions to diversify their crop production (equation 3). In a systematic manner, we build up the model by first including our weather shock variables and then we added the distance to market as a quadratic in column 2 before we introduced the other control variables (column 3).

The coefficients for weather shock appears significantly associated with households' decisions to diversify the number of crop species or crop groups grown. Negative weather shocks are associated with a decrease in CD as the coefficient of the absolute standardized deviation is negative and significant except in column 3 where it appears positive but insignificant. While positive weather shocks are associated with a decrease in CD in columns 1 and 2, it appears significantly positive in column 3 as the coefficient of the interaction variable with absolute standard weather deviation is positive. A one unit change in absolute standardized rainfall deviation when rainfall shocks are negatively significant can reduce CD but when the rainfall shocks are positive, a one unit change in absolute standardized rainfall deviation when rainfall shocks (deviations) can reduce CD with lesser magnitude than when the shocks are negative in columns 1 and 2. However, in column 3, the average change in CD for a one unit change in absolute rainfall when deviations are positive increase CD by 11.9 percent. Thus, there is a positive association between positive rainfall shocks and CD which implies that households may diversify their crop production portfolio when they receive higher than average rainfalls. This is reasonable given that when crops groups are planted together, they may be introduced sequentially during a 2-3 months' time period.

The coefficient of the market access variables (proxied by distance to market) appears positive and significantly associated with CD across all the columns while the square of the distance to market appears negative and significantly related to CD. The relationship between distance and CD is declining outside the 75th percentile. For half the sample, distance to market increases likelihood of CD, however for the other half of households living farther away, they are less likely to adopt CD. These households are also the one with higher diet diversity.

Table 4: Correlates of Crop Production Diversity (OLS model) where crop diversity is the dependent variable

	Model 1	Model 2	Model 3
Absolute rainfall deviation (*R*)	-.133***	-.154***	.006
	(.019)	(.019)	(.021)
Positive Rainfall dummy (*PR*)	.076**	.072**	-.075**.
	(.034)	(.034)	(.035)

	Model 1	Model 2	Model 3
*R*PR*	.091***	.081**	.113***
	(.032)	(.032)	(.036)
Distance to market (*D*)	-	.006***	.005***
		(.001)	(.001)
Distance to market squared (D^2)	-	-.000***	-.000***
		(.000)	(.000)
Marginal effect of rainfall shock			
- Negative rainfall deviation	-.133***	-.154***	.006
- Positive rainfall deviation	-.042	-.073***	.119***
Marginal effect of distance to market			
- evaluated at 43km		.002***	.002***
- evaluated at 64km		.000	.000
- evaluated at 95km		-.003***	-.002***
Controls include	No	No	Yes
Number of observations	7,885	7,836	7,481
F	40.37	43.11	34.63
Prob>F	0.00	0.00	0.00
R-Squared	0.01	0.02	0.11

Notes: Robust standard errors in parentheses. Statistical significance denoted at ***p < 0.01, **p < 0.05, *p < 0.1.
Source: Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.

Association Between Crop Diversity and Farm Profit

Table 5 presents the fixed effects (FE) regression result to estimate the association between crop diversification and farm profit (equation 4). Column 1, show the results for the inclusion of CD and weather shocks variables (positive dummy, absolute standardized difference and the interaction between positive dummy and absolute). Distance to the market and the square of the distance to the market was introduced (column 2) before the inclusion of the control variables in column 3. The full regression result with all control variables is provided in appendix B.

Crop diversity appears positive and significantly (p<0.01) associated with increase in farm profit. This is contrary to our a priori expectation that farm profit will increase with specialization. The coefficient of weather shock (absolute standardized rainfall deviation) appears negative and significantly associated with farm profit while the coefficient of the indirect effect of weather shock (interaction between positive dummy and absolute) appears positive and significantly associated with farm profit in all the columns. This suggests that a one unit change in absolute standardized rainfall deviation when rainfall shocks are negative reduce farm profit in all models, and a one unit change in absolute standardized rainfall deviation when rainfall shocks (deviations) are positive is associated with increased farm profit in all models significantly different from zero.

In addition, the coefficient of market access (proxied by distance to market) appears positive and significantly associated with farm profit across columns 1, 2 and 3. This result suggests that farm profit increase as we move farther away from the major market. The marginal effect reveals that farm profit increases with increase in distance to market of up to about 95km (column 3) away from the market with a diminishing marginal effect subsequently. For the marginal effect of distance to market, CD increases with an increase in the household's distance to market but later declines when households are located farther away from the market. For example, the marginal effect of households at 43km distance away from the market on the log of farm profit is 2.6 percent while at 70km away from the market, the marginal effect is 1.0% and 1.5% in column 2 and 3 and significant at $p<0.05$ respectively.

Table 5: Correlates of Farm profit using a Two-Way Fixed Effects Model

	Model 1	**Model 2**	**Model 3**
Crop Diversity (CD)	.199***	.195***	.161***
	(.027)	(.027)	(.028)
Absolute rainfall deviation (R)	-.451***	-.478***	-.368***
	(.116)	(.116)	(.130)
Positive rainfall dummy (PR)	.146	.161*	.153
	(.093)	(.093)	(.098)
R*PR	1.212***	1.216***	.991***
	(.197)	(.198)	(.229)
Distance to market (D)		.035**	.045**
		(.014)	(.021)
Square distance to market (D^2)		-.000*	-.000*
		(.000)	(.000)
Marginal effect of rainfall shock			
- Negative rainfall deviation	-.451***	-.478***	-.368***
- Positive rainfall deviation	.761***	.738***	.628***
Marginal effect of distance to market			
- evaluated at 43km		.020***	.026**
- evaluated at 64km		.013**	.017*
- evaluated at 95km		.002	.004
Control	No	No	Yes
Number of observations	6,120	6,074	5,826
F	30.18	21.30	7.26
Prob > F	0.00	0.00	0.00
Mean of farm profit for CD=1	58,659	58,659	58,659

Note: Robust standard errors in parentheses. Statistical significance denoted at ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
Source: Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.

VI. Discussion

Crop diversification is a common practice among smallholder households in Nigeria like most of other developing economies who are often faced with imperfect market situations. Our result reveal that crop diversification is insignificantly associated with improved household welfare when at the market but the marginal effect (magnitude) of CD at various distances (km) away from the market appears positive and significantly associated with increased (PCE), household dietary diversity score (HDD) and food consumption score (FCS) in all cases except for PCE where the association appears negative during the postharvest season. There is insignificant association between CD and the anthropometric child well-being (HAZ and HAD) either right at the market or at any distance away from the market. This largely supports the argument that there is a strong positive association between CD and household well-being (Debela et al., 2021; Murendo et al., 2018; Adjimoti and Kwadzo, 2018; Mango et al., 2018; Jones et al., 2014) particularly when the household are located far away from the market. Hirvonen and Hoddinott (2017) Khonje et al. (2022) and Sibhatu and Qaim (2017) argued that the significance of CD in household welfare disappear with market access as the latter is more important which is contrary to our findings. Likewise, the insignificance of the association between CD and anthropometric measures (HAD and HAZ) may stem from the fact that most of the healthy diet for children are usually of animal origin than crop. Besides, it might take a longer period to clearly observe the effect of CD on child anthropometric well-being. Likewise, Khonje et al. (2022) also found that production diversity (crop and livestock) had a small significant effect on child or adolescent nutrition in Ethiopia, Malawi, Tanzania, and Uganda.

We find that the magnitude of the association between CD at various market distances and household well-being during the post-planting season appears bigger than during the post-harvest season. In checking for the robustness of our analysis, we measure our CD using species count and find consistent result given the direction and significance of the association between CD and household welfare outcomes (see Table 6-8 in the appendix), with the magnitude of the coefficient appearing bigger when species count is used as a proxy for CD. Sibhatu and Qaim (2018a), also argued that when CD is measured using the number of food groups produced, the association are insignificant in most cases but the positive association is significant when species count is used.

Since we cannot affirm that household diversify their crop production portfolio only because of its importance in household welfare, we further unpack the reason for diversification and find that both positive and rainfall shock affects CD differently. As climate uncertainty and changes influence how farmers learn weather signals (Moore 2017; Patel 2023) and farmers place greater weight on recent weather signals when making planting decisions especially in areas with higher weather variation (Kala, 2017). Our findings suggest that smallholder household exposure to positive rain deviation (less rain than historical rainfall averages) reduce CD in all cases while their exposure to negative rainfall (more rainfall) either increase CD but in cases where it reduces CD, it is with a lesser magnitude than when the rainfall shocks are negative. This aligns strongly with the findings of Makate et al. (202) that negative shock in terms of recurrent drought and exposure to relative more severe drought shocks in Zimbabwe may reduce household investment in agricultural production while households may enhance seed use and CD decisions if exposed to less severe or positive shocks.

Likewise, Bellon et al. (2020) found that weather shocks such as rainfall or temperature variability may influence household crop diversity decision in a complex way in Ghana. This result is also consistent with our robustness analysis using species count as a measure of CD with the OLS estimation technique (see Table 9 in the appendix). We also find a positive and significant association between household distance to the major market and CD. We observe a positive association up to an average distance of 70 km away from the major market, which then becomes negative. This agrees with our a priori expectation that smallholder household may likely diversify their crop production portfolio to meet household consumption need when faced with limited market access or imperfect market situation.

We further find a strong positive and significant association between CD and increased farm profit. Contrary to our a priori expectation that farm profit will increase with specialisation, our results contradict this. This may be as a result of the fact that farmers are able to maximise their profits and minimise their cost and risk through crop diversification. Our findings corroborate the thinking that crop diversification increase and stabilize productivity and farm profit margin (Fung et al., 2019; Bedoussac et al., 2015; Matusso et al., 2014). However, all the coefficients are highly significant ($p<0.01$) and large for the species count in the result robustness check than with the number of crop group. This is in line with Makate et al. (2022, 2023) who finds that negative shocks due to persistent drought exposure may lead to a decline in household investment in crop production and CD may improve with positive rainfall shocks. As we also find that less rainfall shock reduces farm profit but positive rainfall shock increase farm profit significantly in all cases. Lastly, we find that household distance to the major market is positive and significantly associated with increase in farm profit but the positive association is up to an average distance of 70 km and then afterwards, the association becomes insignificant. This is ambiguous as we expected market access to be positively linked to increase in farm profit. This finding is also consistent with our robustness analysis result in the appendix (Table 10).

VII. Conclusion and Policy Implications

In this paper, we determine why farmers diversify their crops and its implications on household wellbeing. We further consider the influence of market access (distance to market), shocks and other control variables in driving this association between crop diversification and welfare. We find that crop diversification is a common practice among smallholder households in Nigeria like most of other developing countries which are often faced with imperfect market situation. Specifically in Nigeria, more than 85% of smallholder household diversify their crop production portfolio by growing at least 3 crop species with poor market access as most of them are located at about 67-69km away from the major market as revealed by the Nigeria LSM data for wave 1-3 (2010-2015).

By relying on this panel data set, we employed both OLS and two-way fixed effect panel regression models to understand the association between CD and smallholder household welfare and unpack the reasons why farmers practice CD. Our results show that CD is positive but insignificantly related to smallholder PCE, HDD and FCS more especially during the post-planting season when the households are right at the market. But this association become more important and significant as the households is situated farther away from the market especially for the quality of household diet (HDD and FCS). For example, for households residing 64km from markets (50th percentile), growing an extra crop is associated with only 0.04 additional food groups consumed by the household (HDD) on an average. We find no evidence that CD is associated with more diverse diets (HDD and FCS) in communities adjacent to markets (consistent with the notion that households with market access can treat their production and consumption decisions separately), households that are farther from markets appear to rely in part on the diversity of the crops that they produce for diversity in their diets. However, there is a nonlinear relationship between market access and CD. For households within the median distance from markets (64 km), we find that the number of crop groups grown by households increases with distance from the market, but at a decreasing rate. Positive rainfall shocks increase CD significantly. Lastly, we find CD to be positively associated with increase farm profit which could be one of the pathways through which CD influence household welfare. We also find that households that experience abnormally dry weather tend to have lower farm profits, while those experiencing more rainfall than normal tend to have higher profits. These results suggest that farm profits may be one of the pathways through which CD influences household per capita consumption positively during the post-planting period.

In answering our research questions, some major challenges are the problem of outliers and missing observations. We addressed this by first relying on households that were visited in all rounds across the 3 waves. Secondly, we use robust standard error estimator for all our models and we dropped households with missing observation in our key variable of interest. Lastly, we linearize the variable farm profit and PCE. Areas for potential future research will attempt to determine the benefits of crop diversification mechanism like the various bundles of intercropping system in terms of household welfare and farm profit nexus. Also, we will examine if the bundles of CD combined can sufficiently improve household welfare rather than the individual effect in building smallholder household resilience to climate change.

The policy implication of our findings has shown that out of all adaptation measures, crop diversification is an option that is less expensive with lower investment. Since our result has shown a mixed association between CD and shocks, promoting CD may be a key option to be promoted amongst farmers especially resource poor farmers when faced with either positive or negative shocks. An understanding of the interaction between CD and shock is also important in designing intervention programmes aimed at stimulating the adaptive capacity of farmers to cope with extreme weather events and garner support from the government through early warning information and inputs.

Given the importance of the positive association between CD and farm profit, CD that is market-oriented may likely have a stronger positive effect on household dietary diversity as compared to CD that is more subsistence-oriented. But with the high proliferation of subsistence farming in Nigeria, enhancing production diversity through market access may likely be a development strategy that is promising. Government should improve market access of smallholder households for them to make rational choices on crop diversification decision for optima gain that may likely occur through specialization. There is also a need to enhance the capacity of farmers on the right combination of crops to plant as well as the species counts as this may also stimulate their adaptive capacity and income. From all indication, it is not just market access, and shocks that drive CD, but other control variables also drive these associations.

VII. References

Adjimoti, G. O., & Kwadzo, G. T. M. (2018). Crop diversification and household food security status: evidence from rural Benin. *Agriculture & Food Security*, *7*(1), 1-12.

Alobo Loison, S. (2015). Rural livelihood diversification in sub-Saharan Africa: a literature review. *The Journal of Development Studies*, *51*(9), 1125-1138.

Appiah-Twumasi, M., & Asale, M. A. (2022). Crop diversification and farm household food and nutrition security in Northern Ghana. *Environment, Development and Sustainability*, 1-29.

Arimond, M., Wiesmann, D., Becquey, E., Carriquiry, A., Daniels, M. C., Deitchler, M., ... & Torheim, L. E. (2010). Simple food group diversity indicators predict micronutrient adequacy of women's diets in 5 diverse, resource-poor settings. *The Journal of nutrition*, *140*(11), 2059S-2069S.

Baiyegunhi, L. J. S., Akinbosoye, F., & Bello, L. O. (2022). Welfare impact of improved maize varieties adoption and crop diversification practices among smallholder maize farmers in Ogun State, Nigeria. *Heliyon*, *8*(5), e09338.

Bedoussac, L., Journet, E. P., Hauggaard-Nielsen, H., Naudin, C., Corre-Hellou, G., Jensen, E. S., ... & Justes, E. (2015). Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. *Agronomy for sustainable development*, *35*, 911-935.

Bellon, M. R., Kotu, B. H., Azzarri, C., & Caracciolo, F. (2020). To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana. *World Development, 125*, 104682.

Chakraborty, S., & Newton, A. C. (2011). Climate change, plant diseases and food security: an overview. *Plant pathology*, *60*(1), 2-14.

Chamberlin, J., Jayne, T. S., & Headey, D. (2014). Scarcity amidst abundance? Reassessing the potential for cropland expansion in Africa. *Food Policy*, *48*, 51-65.

Debela, Bethelhem Legesse, Esther Gehrke, and Matin Qaim. "Links between maternal employment and child nutrition in rural Tanzania." *American Journal of Agricultural Economics* 103, no. 3 (2021): 812-830.

Di Falco, S., Penov, I., Aleksiev, A., & Van Rensburg, T. M. (2010). Agrobiodiversity, farm profits and land fragmentation: Evidence from Bulgaria. *Land use policy*, *27*(3), 763-771.

Douyon, A., Worou, O. N., Diama, A., Badolo, F., Denou, R. K., Touré, S., ... & Tabo, R. (2022). Impact of Crop Diversification on Household Food and Nutrition Security in Southern and Central Mali. *Frontiers in Sustainable Food Systems*, *5*.

Fanzo, J. (2017). From big to small: the significance of smallholder farms in the global food system. *The Lancet Planetary Health*, *1*(1), e15-e16.

Frelat, R., Lopez-Ridaura, S., Giller, K. E., Herrero, M., Douxchamps, S., Djurfeldt, A. A., ... & Van Wijk, M. T. (2016). Drivers of household food availability in sub-Saharan Africa based on big data from small farms. *Proceedings of the National Academy of Sciences*, *113*(2), 458-463.

Fung, K. M., Tai, A. P., Yong, T., Liu, X., & Lam, H. M. (2019). Co-benefits of intercropping as a sustainable farming method for safeguarding both food security and air quality. *Environmental Research Letters*, *14*(4), 044011.

Hirvonen, K., & Hoddinott, J. (2017). Agricultural production and children's diets: Evidence from rural Ethiopia. *Agricultural Economics*, *48*(4), 469-480.

Hoddinott, J., & Yohannes, Y. (2002). *Dietary diversity as a food security indicator* (No. 136). International Food Policy Research Institute (IFPRI).

Huang, J. K., Jiang, J., Wang, J. X., & Hou, L. L. (2014). Crop diversification in coping with extreme weather events in China. *Journal of Integrative Agriculture,* 13(4), 677-686.

Isbell, C., Tobin, D., & Reynolds, T. (2021). Motivations for maintaining crop diversity: Evidence from Vermont's seed systems. *Ecological Economics*, *189*, 107138.

Jones, A. D. (2017). Critical review of the emerging research evidence on agricultural biodiversity, diet diversity, and nutritional status in low-and middle-income countries. *Nutrition reviews*, *75*(10), 769-782.

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

Kala, N. (2017). Learning, adaptation, and climate uncertainty: Evidence from Indian agriculture. *MIT Center for energy and environmental policy research working paper*, *23*.

Kant, A. K., Schatzkin, A., Graubard, B. I., & Schairer, C. (2000). A prospective study of diet quality and mortality in women. *Jama*, *283*(16), 2109-2115.

Keenan, M., Ng'ang'a Karanja S., Pamuk, H, Ruben, R. (2021). Smallholder Farming Households' Make-or-Buy Decisions Linking Market Access, Production Risks, and Production Diversity to Dietary Diversity CCAFS Working Paper no. 360. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Keenan, M., Ng'ang'a, S. K., Pamuk, H., & Ruben, R. (2022). Smallholder farming households' make-or-buy decisions: linking market access, production risks, and production diversity to dietary diversity. *Production Risks, and Production Diversity to Dietary Diversity*.

Khonje, M. G., Manda, J., Mkandawire, P., Tufa, A. H., & Alene, A. D. (2018). Adoption and welfare impacts of multiple agricultural technologies: evidence from eastern Zambia. *Agricultural Economics*, *49*(5), 599-609.

Khonje, M. G., Ricker-Gilbert, J., Muyanga, M., & Qaim, M. (2022). Farm-level production diversity and child and adolescent nutrition in rural sub-Saharan Africa: A multicountry, longitudinal study. *The Lancet Planetary Health*, *6*(5), e391-e399.

Kiani, A. K., Sardar, A., Khan, W. U., He, Y., Bilgic, A., Kuslu, Y., & Raja, M. A. Z. (2021). Role of Agricultural Diversification in Improving Resilience to Climate Change: An Empirical Analysis with Gaussian Paradigm. *Sustainability*, *13*(17), 9539.

Labeyrie, V., Renard, D., Aumeeruddy-Thomas, Y., Benyei, P., Caillon, S., Calvet-Mir, L., ... & Reyes-García, V. (2021). The role of crop diversity in climate change adaptation: Insights from local observations to inform decision making in agriculture. *Current Opinion in Environmental Sustainability*, *51*, 15-23.

Lin, B. B. (2011). Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience*, *61*(3), 183-193.

Makate, C., Angelsen, A., Holden, S. T., & Westengen, O. T. (2022). Crops in crises: Shocks shape smallholders' diversification in rural Ethiopia. *World Development*, *159*, 106054.

Makate, C., Angelsen, A., Holden, S. T., & Westengen, O. T. (2023). Evolution of farm-level crop diversification and response to rainfall shocks in smallholder farming: Evidence from Malawi and Tanzania. *Ecological Economics 205,* 107736

Makate, C., Wang, R., Makate, M., & Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change. *SpringerPlus*, *5*(1), 1-18.

Mango, N., Makate, C., Mapemba, L., Mapembamm, L., and Sopo, M. (2018). The role of crop diversification in improving household food security in central Malawi. *Agric. Food Secur.* 7, 7. doi: 10.1186/s40066-018-0160-x

Moore, F. C. (2017). Learning, adaptation, and weather in a changing climate. *Climate Change Economics*, *8*(04), 1750010.

Mulwa, C. K., & Visser, M. (2020). Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. *World Development*, *129*, 104906.

Murendo, C., Nhau, B., Mazvimavi, K., Khanye, T., and Gwara, S. (2018). Nutrition education, farm production diversity, and commercialization on household and individual dietary diversity in Zimbabwe. *Food and Nutrition Research*, 62:1–13.

Popkin, B. M., & Slining, M. M. (2013). New dynamics in global obesity facing low-and middle-income countries. *Obesity reviews*, *14*, 11-20.

Powell, B., Bezner Kerr, R., Young, S. L., & Johns, T. (2017). The determinants of dietary diversity and nutrition: ethnonutrition knowledge of local people in the East Usambara Mountains, Tanzania. *Journal of ethnobiology and ethnomedicine*, *13*(1), 1-12.

Qaim, M. (2017). Globalisation of agrifood systems and sustainable nutrition. *Proceedings of the Nutrition Society*, *76*(1), 12-21.

Renard, D., & Tilman, D. (2019). National food production stabilized by crop diversity. *Nature*, *571*(7764), 257-260.

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

Sibhatu, K. T., & Qaim, M. (2017). Rural food security, subsistence agriculture, and seasonality. *PloS one*, *12*(10), e0186406.

Sibhatu, K. T., & Qaim, M. (2018a). Farm production diversity and dietary quality: linkages and measurement issues. *Food Security*, *10*, 47-59.

Sibhatu, K. T., & Qaim, M. (2018b). Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. *Food Policy*, *77*, 1-18.

Sibhatu, K. T., Krishna, V. V., & Qaim, M. (2015). Production diversity and dietary diversity in smallholder farm households. *Proceedings of the national academy of sciences*, *112*(34), 10657-10662.

Singh, I., Squire, L., & Strauss, J. (1986) *Agricultural Household Models: Extensions, applications, and policy.* Baltimore, MD: Johns Hopkins University Press.

Vernooy, R. (2022). Does crop diversification lead to climate-related resilience? Improving the theory through insights on practice. *Agroecology and Sustainable Food Systems*, 1-25.

Appendix

Table 6: Summary statistics for the Household variables

	2010/2011		2012/2013		2015/2016		
	(N=740 HH)		(N=613 HH)		(N=643 HH)		Pooled
	Mean	std. dev.	mean	std. dev.	mean	std. dev.	
Outcome variable							
Post-harvest							
Total consumption expenditure (₦) **	70,532.6	53.490.2	61,226.8	57,420.1	67,291.15	56,087.7	66,5695.4
HDD (7 food groups)	5.69	1.00	5.91	1.00	6.15	.85	5.91
Food consumption score	24.11	8.78	22.97	9.63	24.71	9.24	23.96
Post-planting							
Total consumption expenditure (₦) **	54,952.1	41,183.7	64,796.1	84,105.69	64,879.5	66,799.7	61,360.4
HDD (7 food groups)	5.46	1.21	5.61	1.16	6.06	.90	5.71
Food consumption score	23.80	10.93	22.45	9.51	24.24	9.80	23.54
Anthropometric well-being (HAZ)	-1.44	1.86	-1.02	1.63	-1.22	2.16	-1.21
HAD	-5.37	6.72	-3.85	5.91	-4.31	7.43	-4.43

N (HAZ and HAD) =290, 341, and 416 for wave 1, 2, and 3 respectively

Table 7: Robustness Check for the Association between CD and Species Count
Two-Way Fixed Effects Model

	Post planting			Post harvest		
	PCE	HDDS	FCS	PCE	HDDS	FCS
Crop diversity (CD)	.004	.069	1.215***	084***	.065	.696*
	(.027)	(.043)	(.407)	(.022)	(.040)	(.365)
Distance to market (D)	.000	-.006	.027	012*	.016	.116
	(.008)	(.019)	(104)	(.006)	(.024)	(.159)
Distance to market squared (D^2)	-.000	.000	-.000	-.000**	-.000	-.001
	(.000)	(.000)	(.001)	(.000)	(.000)	(.001)
CD*D	.001	.000	-.008	-.003***	-.002	-.013
	(.001)	(.001)	(.011)	(.001)	(.001)	(.010)
CD*D^2	-.000	-.000	.000	.000***	.000	.000
	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
Marginal effect of CD						
- evaluated at 43km from market	.026***	.075***	.949***	.001	.016	.294**
- evaluated at 64km from market	.032***	.078***	.883***	-.020**	.006	.210*
- evaluated at 95km from market	.035***	.082***	.862***	-.023**	.007	.218*
Control a	Yes	Yes	Yes	Yes	Yes	Yes
Constant	10.571***	4.844***	7.579	11.128***	5.097***	18.002**
	(.414)	(1.024)	(5.128)	(.367)	(1.354)	(8.785)
Number of observations	7,481	7,467	7,467	7,543	7,475	7,475
F	24.96	14.28	11.15	24.20	4.18	2.58
Prob >F	0.00	0.00	0.00	0.00	0.00	0.00

Note: robust standard errors in parentheses. Statistical significance denoted at ***p < 0.01, **p < 0.05, *p < 0.1. Natural log of per capita expenditure, Household Dietary Diversity, and Food Consumption Score are denoted as lnPCE, HDD and FCS, respectively. SC, CD is measured by species count and D denotes Distance to market in KMs respectively. **Source:** Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.

Table 8: Robustness Check for the Association between CD and Anthropometric wellbeing (Child)

Two-Way Fixed Effects Model

	HAZ	HAD
Crop diversity (CD)	-.148	-.476
	(.149)	(.556)
Distance to market (D)	-.015	-.131
	(.054)	(.182)
Distance to market squared (D^2)	.000	.001
	(.000)	(.001)
CD*D	.004	.011
	(.004)	(.015)
CD*D^2	-.000	-.000
	(.000)	(.000)
- evaluated at 43km from market	-.024	-.114
- evaluated at 64km from market	-001	-.031
- evaluated at 95km from market	-.011	-.020
Control a	Yes	Yes
Constant	-.056	-1.119
	(3.191)	(10.927)
Number of observations	4,462	4,462
F	1.54	1.42
Prob > F	0.05	0.09

Note: robust standard errors in parentheses. Statistical significance denoted at ***p < 0.01, **p < 0.05, *p < 0.1. CD is measured by species count, Distance to market in KMs.

Source: Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.

Table 9: Robustness Check for the Association between Rainfall shock, market access and CD

OLS Estimation

	Column 1	Column 2	Column 3
Absolute rainfall deviation (R)	-.152**	-.176***	-.038
	(.036)	(.037)	(.041)
Positive Rainfall dummy (PR)	.185***	.189***	-.105
	(.060)	(.060)	(.061)
R* PR	-.196***	-.225***	.015
	(.058)	(.058)	(.065)
Distance to market (D)	-	.016***	.016***
		(.001)	(.001)
Square distance to market (D^2)	-	-.000***	-.000***
		(.000)	(.000)

	Column 1	Column 2	Column 3
Marginal effect of market distance			
- evaluated at 43km from market		.007***	.008***
- evaluated at 64km from market		.002**	.004***
- evaluated at 95km from market		-.005***	-.002***
Control [a]	No	No	Yes
Constant	3.357***	2.934***	1.673***
	(.035)	(.063)	(.161)
Number of observations	7,885	7,836	7,481
F	25.47	46.40	43.04
Prob>F	0.00	0.00	0.00

Note: robust standard errors in parentheses. Statistical significance denoted at ***p < 0.01, **p < 0.05, *p < 0.1.

Source: Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.

Table 10: Robustness Check for the Association between crop diversity and farm profit

	Column 1	Column 2	Column 3
Species count	.179***	.178***	.162***
	(.015)	(.015)	(.015)
Absolute rainfall deviation (R)	-.495***	-.521***	-.400***
	(.115)	(.115)	(.129)
Positive rainfall dummy (PR)	.148	.162*	.156
	(.090)	(.091)	(.096)
R*PR	1.316***	1.322***	1.059***
	(.196)	(.196)	(.226)
Distance to market (D)		.036***	.047**
		(.013)	(.021)
Square distance to market (D^2)		-.000*	-.000**
		(.000)	(.000)
- evaluated at 43km from market		.021***	.028**
- evaluated at 64km from market		.014***	.019**
- evaluated at 95km from market		.003	.005
Control [a]	No	No	Yes
Constant	9.998***	8.587***	8.621***
	(.090)	(.487)	(1.051)
Number of observations	6,120	6,074	5,826
F	54.90	37.56	10.78
Prob > F	0.00	0.00	0.00

Note: robust standard errors in parentheses. Statistical significance denoted at ***p < 0.01, **p < 0.05, *p < 0.1.

Source: Authors' calculation from the 2010 – 2015 LSMS Nigeria Data.