Regenerative Agriculture for Dietary Diversity and Food Security

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Abstract

Regenerative agriculture (RA) is a grassroot approach to farming that uses soil conservation as an entry point to regenerate and contribute to multiple ecosystem services. It has the potential to build farm system resilience, improve soil health and soil carbon sequestration and reduce the emission of greenhouse gases. They can also increase land productivity with ensuing implications on livelihoods and welfare, but little work considers their food and nutrition security implications. We study a bundle of soil-focused agronomic practices often framed as RA in recent policy debates and examine their association with diets and food security. Employing a two wave panel data from Zambia with well suited estimation strategies, we show a positive association between RA and household dietary diversity scores (HDDS). We also observe a positive association between RA and a 24-hour weighted food consumption score. Practices such as contour farming, crop rotation, and mulching are positively correlated with improved dietary quality and enhanced food security. To explain the positive link between RA, diets and food security, we identify farm production diversity, market participation, off-farm participation, and income as potential pathways. Heterogeneity analysis of the HDDS food groups shows a positive association between RA and consumption of eggs, pulses, roots and tubers, and fruits and vegetables. This strengthens the finding that farm production diversity could be one of the pathways linking RA and food security. Relatedly, the negative association between RA and the consumption of dairy products bolsters the market participation pathway. Our findings lend credence to the strengthening of RA and promoting its adoption in smallholder farming systems.

Keywords: regenerative agriculture;; dietary diversity; income; food security
JEL codes: I12, I14, O13, Q18

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1. Introduction

In this paper, we examine a bundle of soil-focused agronomic practices often framed as RA in recent policy debates and examine their association with diets and food security. In doing so, we also examine the association between RA and farm production diversity, market participation, off-farm participation and income and further assess how these outcomes relate to dietary diversity and food security. Our measures of dietary diversity and food security are the standard household dietary diversity score (HDDS) and a weighted food consumption score over 24hours. In the interest of underscoring some heterogeneities, especially in the consumption of food groups, we perform some disaggregated regressions modelling the association between RA and the individual food groups in the HDDS. We also examine how the different RA practices are associated with diets and the 24 hours weighted food consumption score. We rely on a two-wave panel nationally representative dataset from Zambia and employ different empirical strategies suited for panel data such as the Mundlak Chamberlain device (correlated random effect model) and the household fixed effect estimator.

We report four important findings. First, we establish a positive association between RA and household dietary diversity score which represents dietary quality especially with the consumption of some nutritious and healthy foods. Contour farming, crop rotation, and mulching are positively correlated with improved dietary quality and enhanced food security. Second, we also show a positive association between RA and food consumption score (24 hours). Third, we identify farm production diversity, market participation, off-farm participation and income as possible mechanisms explaining the association between RA, diets and food security. We establish a positive association between RA and these pathway outcomes as well as between these pathway outcomes and dietary diversity. Finally, in terms of the heterogeneity, we find a positive association between RA and the consumption of pulses, roots and tubers, fruits and vegetables and eggs. This strengthens the premise that farm production diversity may indeed be an important pathway linking RA, dietary diversity and food consumption. Further confirming this is the negative association between RA and the consumption of dairy products – which for the most parts are usually purchased from markets (Ameye et al., 2021; Dzanku et al., 2024).

Our study contributes to several areas of extant literature in three main ways. The first addition is to the growing literature on RA and their implications which has not been extensively studied beyond some conceptual linkages (Dabalen et al., 2024; Wilson et al., 2025). We provide evidence on the association between RA with dietary diversity and food security. Here, we recognize the possible overlap between RA and other concepts such as climate-smart agriculture (CSA) and conservation agriculture which have been extensively studied (Arslan et al., 2015; Amadu et al., 2020; Liang et al., 2021; Vatsa et al., 2023). Our point of departure is in focusing on RA practices that have somewhat little overlap with CSA. For instance, we do not consider the use of climate resilient crop varieties and irrigation which are some of the most important practices under CSA (Tabe-Ojong et al., 2023). While RA practices share similarities with these other concepts and draw from indigenous farming systems, they differ due to their unique philosophies and objectives (Dabalen et al., 2024). The second contribution is in how we measure and estimate RA – looking at a bundle of different practices besides the independent use of these practices. Many empirical studies on the implication of various sustainable agricultural practices have not only considered the use of these practices from an extensive basis but have also limited these practices to usually to three or less practices (Malate et al., 2019; Amadu et al 2020; Teklewold et al., 2019; Tabe-Ojong et al., 2023). In our case, we consider 9 RA practices (intercropping, crop rotation, earth bunds, minimum tillage, agroforestry, terraces, mulching, cover cropping and contour farming) that are soil centric with implications on soil health and regeneration.

2. Data and estimation variables

2.1 Farm household survey

Our analysis is based on the Rural Livelihood household survey which is a three-wave panel survey conducted in Zambia in 2012, 2015 and 2019. The survey was carried out by the Indaba Agricultural Policy Research Institute (IAPRI) with support from the Ministry of Agriculture and the Zambia Statistics Agency. The survey is based on a stratified two stage design wherein primary sampling units were defined and randomly selected. The primary sampling units in this case were enumeration areas with a minimum of 30 households (Figure 2). Following this, a detailed household listing exercise was undertaken to enable stratification. Households were stratified based on different aspects of crop production including area under crop production as well as livestock ownership and source of income. After the household listing and stratification, about 20 households were randomly selected from the enumeration areas.

In the first survey year, about 442 enumeration areas were covered in all the 10 provinces and a total of about 8839 households were interviewed. In 2015 and 2019, these households were followed and reinterviewed with 7933 and 7241 households successfully reached in these years. However, we only relied on the two-wave sample in 2015 and 2019 given that the 2012 survey has no information on food consumption. The surveys in 2015 and 2019 included a detailed 24-hour recall of the various food groups consumed by households. The survey contained detailed sections on different aspects of farm production and livestock, income and asset ownership, crop cultivation, commercialization, and adoption of regenerative agricultural practices including different shocks such as droughts, floods, as well as pests and diseases. More insights into the sampling and survey design can be found in the RALS survey report (IAPRI, 2020; Mulenga et al., 2021). The survey is nationally representative of all the 10 provinces (Central, Copperbelt, Eastern, Luapula, Lusaka, Muchinga, Northern, Northwestern, Southern, and Western provinces) in the countries.

3. Estimation strategy

To estimate the association between RA, dietary diversity and food security, we estimate panel data regressions of the form:

$$Y_{it} = RA_{it}\beta + \boldsymbol{X_{it}\delta} + d_t + c_i + \varepsilon_{it} \quad (1)$$

Where Y_{it} refers to dietary diversity (HDDS) and the weighted 24-hour food consumption score for farm household *i* over time *t*. We also perform some estimations on the individual food groups of the household dietary diversity to uncover some potential heterogeneities. RA represents the 9 RA practices outlined above. Although we treat these practices as binary variables, previous studies have shown that households tend to adopt them collectively rather than separately (Tabe-Ojong et al.). 2023). The bundling of these practices can be expected to lead to better economic and environmental outcomes, especially as these practices are complementary and could offer additive impacts. Given this, we count the number of practices adopted by households to define our key variable of interest[2]. In addition to counting RA practices, we construct a principal component analysis index and conduct robustness check using this.

[2] The average number of RA practices used by households is 2.

Our parameter of interest is β which signifies the association between RA, diets and food security. $\boldsymbol{X_{it}}$ represents a vector of controls which we used to improve the precision of the regression estimates and reduce the possible pathways linking RA, diets and food security. These controls are age and educational level of the household head, gender, household size, access to credit, area of cultivation, total land owned, farm input subsidy participation, droughts, floods, shocks, pests and diseases, asset ownership and livestock ownership. d_t is the time fixed effect, ε_{it} is the error term and c_{1i} refers to time invariant unobserved heterogeneity. This refers to variables such as risks, skills, preferences and motivation which are difficult to measure or have not been measured. Controlling for this is usually not trivial but since we have panel data, we can rely on different panel estimators to control for this.

After estimating the association between RA and dietary quality and food security, we are also interested in understanding the pathways or mechanisms linking these two. We consider four outcomes as outlined in the conceptualization – farm production diversity, market participation, off-farm participation and income. Given this, we run some further regressions of the form:

$$P_{it} = RA_{it}\beta + \boldsymbol{X_{it}\delta} + d_t + c_i + u_{it} \quad (2)$$

All the symbols are as previously defined with P_{it} representing the four pathway outcomes and u_{it} the stochastic error term. We again estimate both the CRE and the FE estimator to control for time invariant unobserved heterogeneity. To fully confirm these four outcomes as possible pathways, we perform some additional regressions linking these pathways and the dietary quality and food security outcomes. These regressions are of the form:

$$Y_{it} = P_{it}\beta + \boldsymbol{X_{it}\delta} + d_t + c_i + v_{it} \quad (3)$$

All symbols are still as previously defined with v_{it} representing the stochastic error term. A positive association between RA and the four pathway outcomes as well as between the pathway outcomes and dietary quality and food security would confirm that these four outcomes are some of the pathways explaining the relationship between RA and dietary quality and food security.

We perform several robustness checks including the two-stage least squares approach where we specify instrumental variables to identify the relationship between RA and food security as well as the other pathway variables. We also used an index generated from the principal component analysis in place of the count of the number of RA practices used.

5. Results and Discussion

5.1 Descriptive insights

Figure 3 shows the summary statistics of the outcome variables – HDDS of both the 12 and 9 food groups as well as the 14-hour weighted food consumption score. We present the mean of both the pooled data and the different panel years. Households report a food consumption score of about 11 and a household dietary diversity score of about 6 foods. After excluding some of the less nutritionally valued foods, the mean reduces to about 4 foods per household. This suggests that the nutritional bundle of households are diversified and are also healthy and nutritionally valued.

Figure 4 Descriptive summary of RA practices

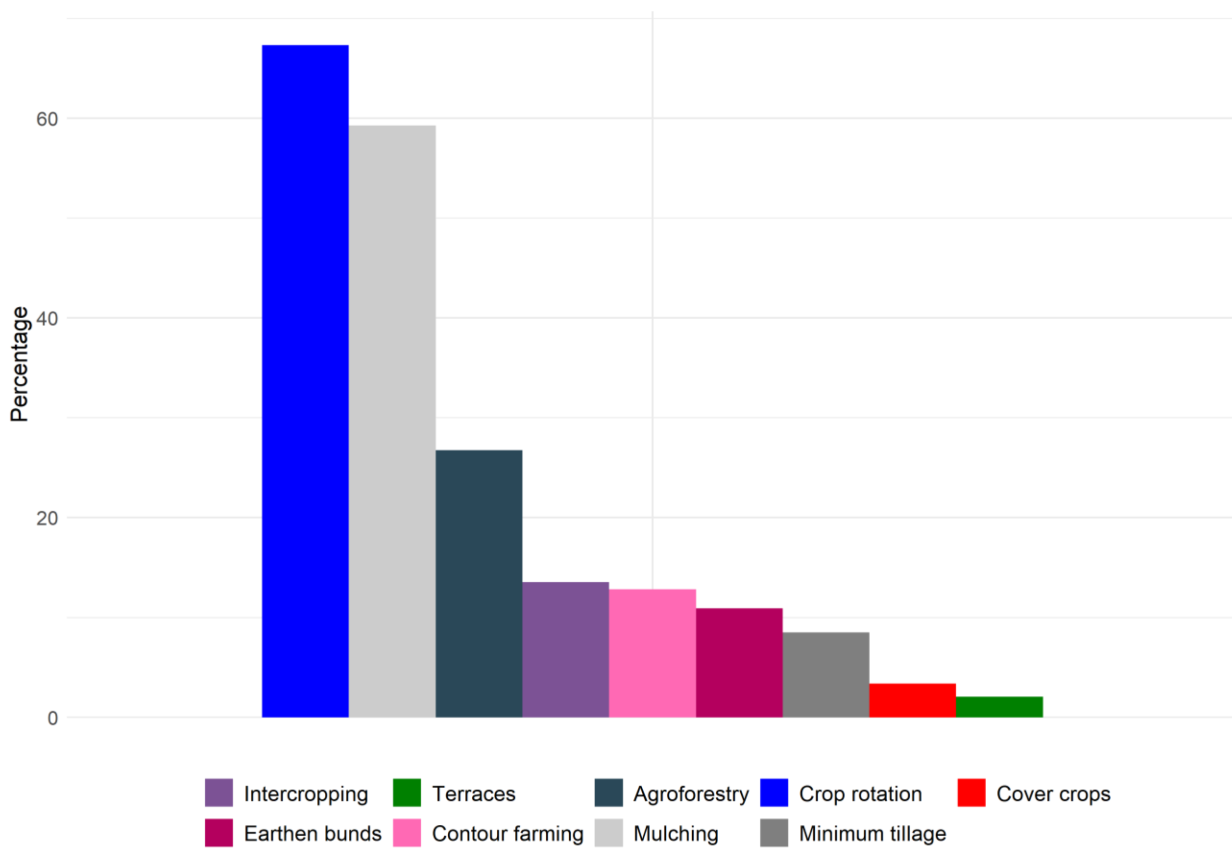


Figure 4 shows the summary insights of the RA practices used by households. The most used practices are crop rotation, mulching, agroforestry, and intercropping. Over time, we see some large increases in the use of some RA practices such as crop rotation and agroforestry.

Agroforestry involves the integration of different kinds of trees and shrubs into farm production. These trees capture CO_2 from the atmosphere which they store in their biomass. Some of these trees are leguminous with the ability to fix atmospheric nitrogen while also sequestering carbon in the soil and storing soil organic carbon. Table 1 provides the summary statistics of the key model variables including the outcomes and variables of interest.

Table 1. Summary statistics of key model variables

	2015 (N=6,626)	2019 (N=6,626)	Total (N=13,252)
HDDS12	5.90 (2.14)	6.13 (1.83)	6.01 (2.00)
HDDS9	4.31 (1.47)	4.05 (1.37)	4.18 (1.43)
FCS (24-hours)	10.64 (4.68)	9.89 (4.34)	10.28 (4.54)
Crop diversification	2.68 (1.26)	2.52 (1.29)	2.60 (1.28)
Market participation (1/0)	0.76 (0.43)	0.72 (0.45)	0.74 (0.44)
Off-farm activity (1/0)	0.49 (0.50)	0.59 (0.49)	0.54 (0.50)
Income (sine transformed)	6.50 (2.30)	8.12 (1.34)	7.31 (2.05)
RA (count)	1.79 (1.45)	2.43 (1.11)	2.11 (1.33)
RA index (transformed)	0.18 (0.15)	0.26 (0.12)	0.22 (0.14)
Asset index	3.02 (1.43)	3.01 (1.42)	3.01 (1.42)
Livestock (TLU)	2.75 (8.23)	2.95 (7.83)	2.85 (8.03)
Head is male (1/0)	0.79 (0.41)	0.76 (0.43)	0.78 (0.42)
Educational level (years)	6.05 (3.91)	6.08 (3.90)	6.06 (3.91)
Age of household head (years)	49.07(14.53)	52.30 (14.20)	50.68 (14.45)
Household size (num)	7.17 (3.00)	7.20 (3.01)	7.18 (3.01)
Credit access (1/0)	0.17 (0.38)	0.18 (0.38)	0.17 (0.38)
Cultivated land (hectares)	2.29 (4.36)	2.34 (2.62)	2.32 (3.60)
Land size (hectares)	4.92 (11.22)	5.63 (16.25)	5.28 (13.97)
FISP participation (1/0)	0.51 (0.50)	0.50 (0.51)	0.50 (0.51)
Droughts (1/0)	0.10 (0.30)	0.13 (0.33)	0.11 (0.32)
Floods (1/0)	0.01 (0.09)	0.02 (0.12)	0.01 (0.11)
Pests (1/0)	0.01 (0.12)	0.03 (0.16)	0.02 (0.14)
Shocks (1/0)	0.12 (0.32)	0.16 (0.37)	0.14 (0.35)

Notes: FISP stands for farm input subsidy program. Asset index was constructed using principal component analysis from which 5 quantiles were then constructed. HDDS stands for household dietary diversity score while FCS stands for the 24-hour weighted food consumption score. RA stands for regenerative agriculture.

5.2 Regenerative agriculture, dietary diversity and food security

We begin by showing the association between RA and dietary diversity based on the consumption of both the 12 and 9 food groups. As shown in Table 2, we observe a positive association between RA and dietary diversity when considering both the standard score and the healthy food groups. The adoption of RA is associated with higher dietary diversity. The coefficients are also economically meaningful as any additional RA adopted is associated with an increase in household dietary diversity (0.066) which is equivalent to a 1% increase relative to the mean. For the restricted consumption of healthy food groups, this is about 0.05 equivalent to 1.2%. Our study corroborates existing studies on the positive association between soil and water conservation practices, mulching and crop diversification with dietary diversity (Hasan et al., 2018; Teklewold et al., 2019; Issahaku et al., 2020; Haq et al., 2021).

Table 2 Regenerative agriculture and dietary diversity

	(1) HDDS12	(2) HDDS12	(3) HDDS9	(4) HDDS9
Regenerative agriculture	0.122***	0.066***	0.084***	0.050***
	(0.013)	(0.013)	(0.010)	(0.010)
Observations	13,252	13,252	13,252	13,252
Number of panels	6,626	6,626	6,626	6,626
Additional controls	No	Yes	No	Yes
Village FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: HDDS12 refers to household dietary diversity score based on the standard 12 food groups while HDDS9 refers to the 9 food groups.

We go ahead to look at the association between RA, and food security measured through the 24-hour weight food consumption score. Table 3 shows these results where we move from the parsimonious regression to one with different controls and fixed effects. We find a bigger economic and meaningful association (.095) between RA and FCS. Previous studies have shown a positive association between intercropping and other agronomic practices with the food consumption score in different countries of the Sahel and Gulf of Guinea in Ghana, Mali and Nigeria (Tabe-Ojong et al., 2023). These insights on food security have also been shown in other farm systems where different aspects of RA are associated with food and nutrition security (Issahaku and Abdulai, 2019; Vatsa et al., 2023).

Table 3 Regenerative agriculture and food consumption

	(1) FCS (24hours)	(2) FCS (24 hours)	(3) FCS (24 hours)
Regenerative agriculture	0.089***	0.095***	0.106***
	(0.027)	(0.027)	(0.039)
Observations	13,252	13,252	13,252

Number of panels	6,626	6,626	6,626
Additional controls	Yes	Yes	Yes
Village FE	Yes	No	No
Year FE	Yes	Yes	No
Model	CRE	CRE	FE

5.3 Exploring correlational patterns consistent with possible pathways

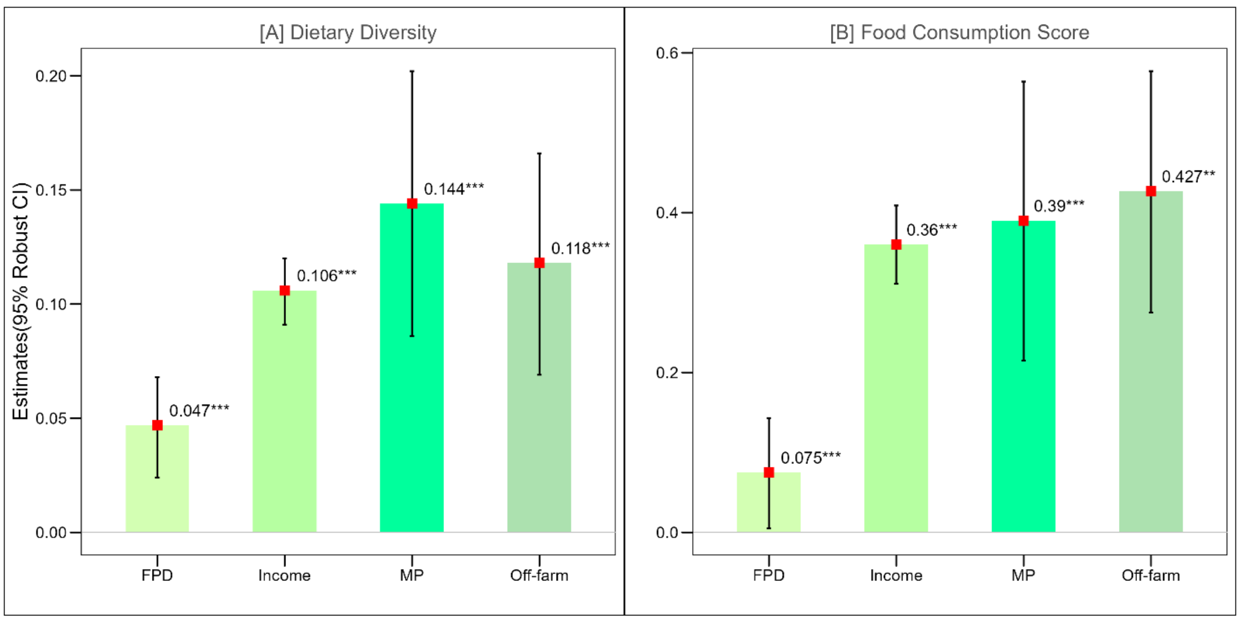
After establishing a positive association between RA, dietary diversity and food security, we delve into some heterogeneity analysis to understand what could be explaining this positive relationship. We examine the role of four pathway outcomes – farm production diversity, market participation, off-farm participation, and household income. Farm production diversity is measured as the number of crops cultivated by households. Market participation captures how market-oriented households are in terms of participating in markets. It is measured as a dummy together with off-farm participation which refers to participation in off-farm activities. Household income is the total of all the income sources of the household. We show a positive association between RA and farm production diversity, market participation, off-farm income participation and household income (Table 4). This suggests that RA has productive, markets, labour, and economic implications. These insights are in line with the tenets of CSA and RA as they are expected to increase production diversity, stir participation in markets, increase participation in off-farm income activities and by so doing increase smallholder incomes. The association between RA and farm production diversity is intuitive as RA practices such as crop rotation and intercropping have been argued to stir crop diversification which is associated with dietary diversity (Mulenga et al., 2021).

Table 4 Pathways of association

	(1) Production Diversity	(2) Market Participation	(3) Off-farm participation	(4) Income
Regenerative agriculture	0.158***	0.033***	0.009**	0.062***
	(0.009)	(0.002)	(0.004)	(0.013)
Observations	13,252	13,252	13,252	13,252
Number of panels	6,626	6,626	6,626	6,626
Additional controls	Yes	Yes	Yes	Yes
Village FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

On the positive association between RA and market participation, it is possible that these could happen through increases in land productivity. Increases in land productivity would translate to market participation after households have satisfied their food consumption demands (Singh et al., 1986). Previous studies have established a positive association between CSA and yields (Amadu et al., 2020; Vatsa et al., 2023; Tabe-Ojong et al., 2023). Moreover, with access to markets, households could purchase foods that they do not cultivate on their farms, hence increasing their dietary diversity and food security (Mulenga et al., 2021; Chegere and Kauky, 2022).

Figure 5 Pathways of association and food security



Notes: This figure shows the association between farm production diversity (FPD), market participation (MP), off-farm participation and income with both household dietary diversity and food consumption

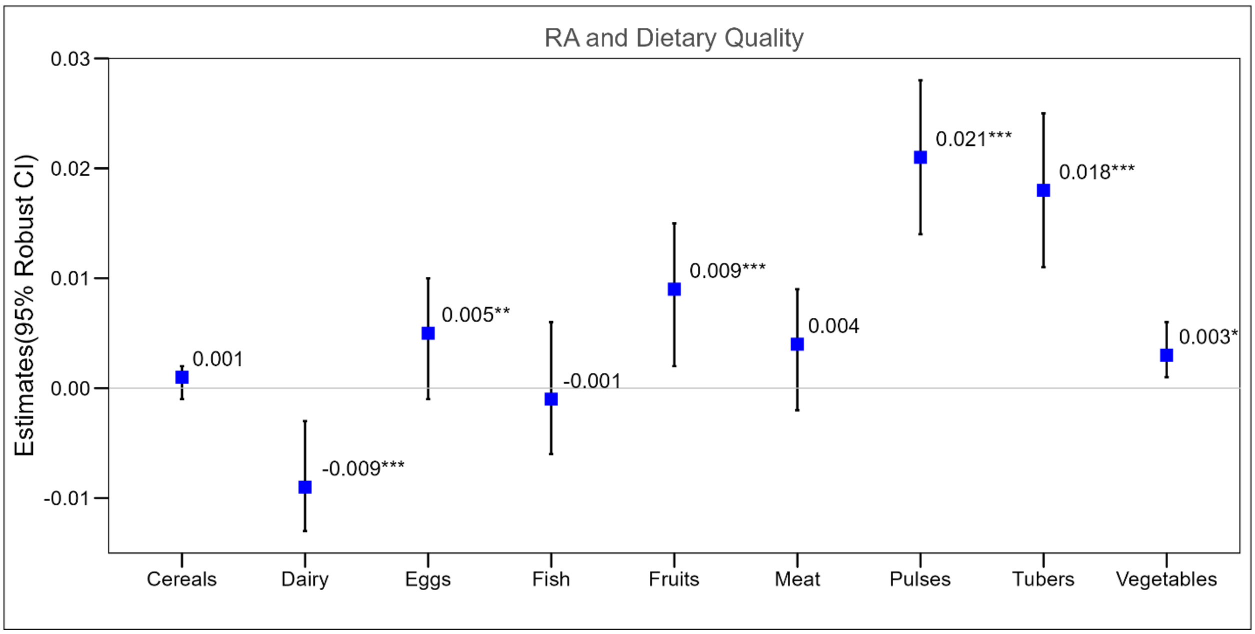
To further confirm the pathways of association, we run some additional regressions between farm production diversity, market participation, off-farm participation and income and the main food consumption and dietary outcomes. Figure 5 shows the results of these associations. We observe a positive association between all the pathway outcomes and dietary diversity and food consumption score. These results further strengthen the insights into the role of farm production diversity, market participation, off-farm participation and income as possible mechanisms linking RA and dietary diversity and food security. Previous studies have established that off-farm participation and income is associated with dietary diversity and food security (Babatunde and

Qaim, 2011; Kuwornu et al., 2018). On the income effects of RA, it could result from pathways such as participating in markets to sell the harvested surplus as well as from off-farm income. With increases in income, households could purchase foods which are usually costly in many markets (Ameye et al., 2021; Dzanku et al., 2024). The findings here bolster existing claims on the income implications of some of these agronomic practices.

5.4 Heterogeneity in dietary quality

In the interest of underscoring heterogeneity in the relationship between RA and the consumption of the different groups, we perform some disaggregated estimations examining how the adoption of RA is associated with the 9 healthy food groups (Figure 6).

Figure 6 Regenerative agriculture and individual food groups



Notes: This figure shows the association between RA and the consumption of the different food groups in the HDDS reduced scale.

For most part, we find a positive association between RA and the consumption of food groups such as fruits and vegetables, pulses, tubers, and eggs. Looking at most of these food groups, we observe additional insights from the pathway outcomes. Particularly, we find evidence that farm production diversity could explain the relationship between RA and the dietary diversity. Of course, access to markets also matters as has been previously highlighted since households cannot typically produce all the food they consume. Under access to well-functioning markets and with the possibility of relaxing the liquidity constraints of households, households can further increase their dietary diversity.

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