IFPRI RWANDA

STRATEGY SUPPORT PROGRAM | WORKING PAPER 10 APRIL 2024

Identifying Farm Typologies in Rwandan Agriculture: A Framework for Improving Targeted Interventions

Gilberthe Benimana, James Warner, Serge Mugabo

CONTENTS

TABLES

FIGURES

1. ABSTRACT

This paper explores the broad spectrum of commercial engagement by Rwandan farmers by grouping farmers according to characteristics of the head of household, the degree of commercialization of their farms, size of livestock holdings and other factors.

We use statistical methodologies, including factor and cluster analysis, combined with existing knowledge of the agricultural sector to define five types of Rwandan farmers, separated into two broad groups. The first group (Group A) includes three types broadly classified as less wealthy, less commercialized, with a net negative gross margin. Within this group the three types of farmers include: Type 1—Less commercialized older male headed households with larger families, Type 2—Better educated, youth headed households, who are more market oriented but have smaller land holdings, Type 3—Older female headed households who produce relatively lower agricultural production value relative to their assets owned.

The second group (Group B) comprises two types of farmers. This group are wealthier, sell more crops with positive gross margins and larger landholdings. More specifically, farm type 4 is commercialized with higher access to agricultural extension services and inputs and farm type 5, also highly commercialized, but has significant livestock holdings as well.

Taken together, these two groups, and five farm types, provide a framework to aid in understanding how commercialization takes place in smallholder Rwandan agriculture. This framework may also help in understanding how potential interventions would be received by various types of Rwanda farmers, thereby facilitating more efficient targeting of agricultural interventions.

2. INTRODUCTION

As Rwanda returns to its rapid growth trajectory following the COVID-19 pandemic and global food, fuel, and fertilizer price crisis, there is an opportunity to adjust the Fifth Strategic Plan for Agricultural Transformation (PSTA 5) investment portfolio so that gains from the agricultural sector and food system contribute more effectively to the transformation of the entire economy. But portfolio adjustments require careful, evidence-based consideration of tradeoffs and synergies across a range of income sources, crop choice, farm types, market conditions, agroecological contexts, and policy goals. In 2022/23, the Government of Rwanda reviewed its midterm progress against PSTA 4 targets. An early point raised in this review process is the need for a deeper, more nuanced understanding of the smallholders that represent PSTA 4's main participants and beneficiaries. While two main categories of smallholders are recognized—subsistence farmers who produce food for their own consumption and commercial farmers who produce for market—the reality is that smallholder livelihoods are more complex than this simple dichotomy suggests. Efforts to understand heterogeneity among these farmers and their commercialization opportunities is essential to designing more efficient and effective policies, investments, and programs.

This study seeks to contribute to such evidence by categorizing smallholder farming in Rwanda and providing more nuanced analysis of farmer typologies[1] and estimates of returns to commercial production systems across determined multiple farmer typologies. These classifications should help organize more realistic farmer commercialization categories along the subsistence – fully commercialized continuum and be useful for improved targeted interventions. Put another way, a general intervention will likely impact our farmer typologies differently and this analysis should help better explain the varied responses.

Characterization of smallholders included the nature, degree, and magnitude of their commercialization and correlates include crop/livestock production portfolios; farm size; use of inputs, technologies, farm management practices; proximity to markets; non-farm activities and enterprises; risk mitigation/risk coping strategies; social connectedness, program participation, as well as other factors. Overall, this research seeks to produce policy-relevant, realistic, data-based typologies of smallholders in Rwanda.

The specific analytical questions that the study answered are as follows.

1. What are salient characteristics of smallholder farmers in Rwanda, and what are the essential characteristics of different groups of commercial smallholders?
2. How can the spectrum of commercial farmers be placed in realistic categories, and what variables contribute to their differing levels of commercial viability?
3. How might these typologies respond/benefit from different policy interventions? Which potential policies would benefit specific each farm typology?

[1] Typology construction provides a statistical method to better understand farmer diversity by delineating groups with common characteristics.

3.MATERIALS AND METHODS

3.1 Statistical and econometric specifications

There are several quantitative approaches to develop farmer typologies that will take us beyond simplistic categorizations of Rwandan farmers as either “subsistence” or “commercial” to potentially improve PSTA 5 targeting and scaling. Alavarez et al. (2014, 2018) provides guidelines for constructing farming system typologies, highlighting (1) the necessity of a well-defined objective in typology construction to guide variable selection, (2) the role that different methods for data collection, data-reduction and clustering techniques can play in typology results. Examples of widely cited farm- and farmer-typologies include Tittonell et al. (2010, 2005a,b), who categorize farm-household diversity based on a functional typology of livelihood strategies in several east African countries, and analyze the influence of this diversity on soil fertility to suggest ways of better targeting agricultural interventions., Giller et al, (2011, 2006) provides a structured, system-analytic approach to studying complexity of African farming systems and identifies “best-fit” technologies and practices for farm management.

Statistical methods applied to typology development often include the combination of factor analysis (FA) and principal component analysis (PCA), or cluster analysis (CA), which are tools typically used to analyze data with a large number of quantitative characteristics (“dimensions”) per observation by reducing dimensionality, increasing interpretability, and minimizing information loss in the process. For examples of rural household typologies, see Giller et al. (2011), Pacini et al. (2013), Timler et al. 2014, Bidogeza et al. 2009, and Landais 1998.

A few studies have constructed farm or farmer typologies for Rwanda. One study by Bidogeza et al. (2009), used PCA and CA methodologies to identify farm types in Umutara Province (currently Gatsibo and Nyagatare districts of the Eastern Province). The results characterize different behaviors about agricultural commercialization, and are differentiated by gender, age, education, risk perception, risk attitude, labor availability, land tenure and income. Using a similar set of variables, Hammond et al. (2020) constructed a farm typology designed to facilitate better local efforts to promote agricultural input use and used PCA and CA, and a decision-tree tool to help input use promoters better characterize client-households, prioritize their type of engagement, and redesign input and technology packages. Our typology construction is reflective of these prior studies and their methods but will focus on the selection of variables that reflect market commercialization.

3.2 Sampling and variable selection for typology generation

The data used in this study was collected from a nationally and provincially representative household sample survey-*Rwanda smallholder agriculture commercialization survey* (2022)[2] led by IFPRI in collaboration with MINAGRI and other local partners. Five strata corresponding to the four provinces and Kigali City were sampled using a stratified two-stage cluster sampling frame. The strata indicated a sample size of 2,020 agricultural households that were engaged in agriculture, aquaculture, livestock, or forestry activities in the 2022 agricultural year with total land size of less than 10 hectares.

[2] For more information on Rwanda smallholder agriculture commercialization survey: Overview using selected categorical variables

The survey instrument was constructed using standard modules commonly used for smallholder production and commercialization surveys extracted from prior surveys conducted in Rwanda including the2020 AHS, 2016/17 EICV5, and additional modules adapted from surveys in other countries designed for similar purposes. General areas of information collected related to household demographic characteristics, farm characteristics, land, household assets, access to information, agricultural-related program participation, household migration and experience to shocks.

To capture social-economic factors that would likely be correlated to farmer's commercialization, and following methodological guidelines for farm typology creation, 71 preliminary variables were selected from the survey. These variables are built upon literature regarding farming systems' structure and operations and are all considered as variables commonly found to correlate with agricultural commercialization. We divided the variables into four categories or domains. These four domains include: human, productivity, economic, and environment and social domains, consistent with those used by Signorelli, Azzarri & Haile (2016) in their study on typology characterization of farmers in Malawi. Factor analysis was performed in each category to select the variables that explain the largest portion of the statistical variation in the data.

Human variables - This category of variables was composed of household demographic characteristics including literacy, education level, age and sex of the household head, and household size. These variables were chosen as they were hypothesized to be most associated with commercial engagement.

Productivity variables - This category of variables was composed of land and farm productivity variables and includes landholdings, crop production and animal production related variables.

Economic variables - This category of variables was composed of agricultural production value, and include agricultural return, household income, non-land and productive farm assets, land/non-farm household assets, and household wealth.

Environment and social variables - This category of variables includes farm characteristics and practices, access to information, program participation, household migration experience, and household shocks.

3.3 Methods

This analysis used a combination of factor and cluster analysis to obtain different commercial farm types. Factor analysis is a quantitative methodology that explains the variation in the data by reducing a large number of variables into uncorrelated factors by ranking each variable by its explanatory power and its weighted relative importance within the factor.[3] Cluster analysis is a technique of grouping a set of similar observations into a number of subsets (called clusters) based on the observed values of several variables for each individual or similarity (Sinharay 2010, Alvarez et al. 2018, Charles et al. 2016). The methodologies are detailed below.

1. Factor Analysis

This study first uses factor analysis to reduce the set of socio-economic variables by extracting all their statistical variance into a smaller number of factors to explain the largest portion of the

[3] Annex 1 provides an example using a 2001 study (Cunningham and Maloney 2001).

entire dataset variation.[4] It differentiates the sample in order to identify underlying patterns in data by dividing the dataset into different factors, or dimensions, and categorize the relative statistical variation of contribution of each variable into one of the factors (McDonald 2014, Basilevsky 2009, Mulaik 2009).

We hypothesize that the participation in, and the extent of, commercial production in smallholder households in Rwanda vary significantly according to a range of different factors. In order to provide more accurate typologies, this research uses relevant aspects of prior studies that estimated correlates of smallholder commercialization (Tabe-Ojong et al. 2022, Ogutu, Gödecke and Qaim 2020, Ochieng et al. 2019, Gebremedhin and Jaleta 2010, Jaleta et al. 2009, Boughton et al. 2007, Pender and Alemu 2007).

2. Cluster analysis

Cluster Analysis is a set of data reduction techniques that has the purpose of classifying and grouping objects based on similar characteristics, such that the characteristics of households in the same group are as similar to each other as possible, while the characteristics of households in different groups have a low level of inter-cluster similarity. To establish farm types (clusters) this study used the combination of hierarchical (ward clustering) cluster analysis (HCA) and k-medians clustering methods using selected variables across different domains for clustering efficiency (Młodak, 2021, Chen et al. 2005, Dubes 1988).

Hierarchical clustering is an algorithm that groups similar objects into groups called clusters. The endpoint is a set of clusters, where each one is distinct from each other, and the objects within each cluster are broadly similar to each other. The hierarchical cluster results also create groups/clusters in a tree-like structure – a dendrogram (Nielsen 2016, Everitt, Landau and Leese 2001, Everitt 1993). K-medians clustering (MacQueen 1967) is a well-known non-hierarchical method that iteratively groups a collection of data points into a fixed number of clusters (k) according to their similarities in which each observation belongs to the cluster with the nearest cluster center or centroid (for an example, see Steinley 2006).

We combined hierarchical and k-medians as both methods have varying strengths and weaknesses. For instance, hierarchical clustering identifies groups in a tree-like structure while building a hierarchy of clusters without having fixed number of clusters. This method suffers from computational complexity in larger datasets as it cannot represent distinct clusters with similar expression patterns. Also, as clusters grow in size, the actual expression patterns become less relevant. The K-median clustering method is appropriate for the efficient representation and compression of larger databases, but it employs a pre-specified number of clusters in advance and selects initial centroids randomly, what may cause slight differences in results each time k-medians are computed. This difference is due to its sensitivity to the initial random selection of cluster centers and data outliers (Peterson, Ghosh & Maitra 2018, Steinhaus 1956). Therefore, for the accuracy of this study, we use a hybrid approach by combining the hierarchical clustering and the k-medians methods where k-medians were used to construct the objects in the clusters while hierarchical cluster analysis (HCA) method was

[4] Factors are unobserved variables that summarize the correlation among several observed variables (McDonald 2014).

used to identify an accurate number of clusters to be used (Kassambara 2017, Chen et al. 2010, Chen, Harrison & Pan 2005).

Methodological steps

1. **Reducing dimensionality of variables domains -** Factor analysis was performed on each category/domain - human, productivity, economic, environment and social - to identify variables that explain the largest portion of the statistical variation in the data.
2. **Defining the number of important factors -** Scree plots - simple line segment plots that shows the eigen values for each individual factor - were conducted to define the number of important factors that define well each variable category, within each of the selected factors. Only variables with the highest absolute values of factor loads (factor scores with an eigenvalue greater than 0.5 or smaller than -0.5 were kept as socio-economic variables that explain most of the variation in the data and thus highly relevant in defining the different farm types (McDonald, 2014).
3. **Defining clusters using Principal Component Analysis (PCA) -** The subset of variables obtained from factor analysis. Shortlisted variables within each category of variables were explored through principal component analysis (PCA) to reduce dimensionality in order to identify variables with the greatest explanatory power (most strongly correlated with principal components), and exclude those variables with weaker explanatory power, high regional variation, or logical overlap with other variables (Jolliffe 2002).
4. **Computing the number of clusters (k)** - Hierarchical clustering of the data was used to select the initial partition or clustering, where n objects were defined by a stepwise algorithm and generate a binary tree-like, a dendrogram, with up to *n*–1 nodes. Dissimilarities between clusters of objects were defined and the branches of this tree were cut to choose the appropriate dissimilarity measure that explains most of the variation in the remaining, or non-cut, objects. This activity helped determine the appropriate number of k-clusters.
5. **Computing the center (i.e. the median) of each cluster -** To compute the center of each cluster (i.e. the median), we used the k-medians clustering algorithm on the number of clusters pre-defined in step 4. The algorithm randomly assigns k initial centers and creates k clusters by associating every observation to the nearest cluster center (i.e. centroid).
6. **Computing k-medians -** using the initial cluster centers (defined in step 5), the centroid of each of the k clusters becomes the new centroid of the clustering variables for each cluster's new set of observations. The K-median algorithm re-iterates this process, assigning observations to the nearest center (some observations will change clusters). This process repeats until a new iteration no longer re-assigns any observations to a new cluster. At this point, the algorithm is considered to have converged, and the final cluster assignments constitute the clustering solution, which divides the total sample into a set of defined clusters.
7. **Cluster validation -** To measure the quality of the clusters, we used the silhouette width -a metric that determines the explanatory power of clusters. The procedure calculates and

graphs the silhouette width for the cluster solution given by the K-medians. For each case (a different possible number of clusters resulted from the dendrogram) we define the median distance to other cases, and the median distance to the nearest neighbor cluster to determine which objects lie well within their clusters, and which do not. This determined the quality of the clustering obtained (Kaufman & Rousseeuw 2009, Reynolds et al. 2006). Silhouette width was highest for 5 clusters as it best explains both the balance of explanatory power and ease of interpretation. The Adjusted Rand Index (ARI) was also used to measure the similarities between two data clusters and is calculated using results from ward and K-median clustering. Five clusters were confirmed using the silhouette width methodology, which statistically validates the selection of our five clusters.

8. **Testing the significance of clusters characteristics -** Medians were used to allocate households in different clusters, as determined by K-medians clustering, and t-tests of mean differences were used to compare farm types to measure statistical differences between these clusters (farm types). Data was compiled and analyzed using STATA 18.

4. RESULTS AND DISCUSSION

4.1 Used variables.

The Factor Analysis (FA) results demonstrated the important variables that define different categories/domains, of the 71 variables identified, 35 were selected to be used to create farmer typology/farmer clusters. Those variables were determined to be the most associated with heterogeneity between designated inter-farm household clusters but exhibiting high statistical similarity at the intra-farm household cluster level. Selected variables were household size, age, literacy status and gender of the household head, access to extension services, use of improved inputs, the size of land, tropical livestock unit (TLU), crop production value, agricultural economic returns, percentage crop and livestock sales and a wealth index These identified variables were identified to be socio-economic characteristics that differentiate farm types. Variables are defined below within each domain/category (Annex 2 provides a more technical explanation).

4.2 Farmers' socio-economic and demographic characteristics

Of the 2,020 farm households interviewed; 30 percent were headed by females. The average household size was 4.4 members and had an adult equivalent index of four. The average age of household heads was 48.5 with the majority (79 percent) being 35 years and above (classified as mature). In addition, about two-thirds of the household heads were literate. Regarding the use of fertilizers, an average of 48 percent of farmers used inorganic fertilizers while only 16 percent used pesticides and/or fungicides. The data indicated low participation rates in terms of agricultural practices, access to information, and program participation where only six percent of the households had a member who belonged to Twigire Muhinzi/Mworozi National Extension System,[5] eight percent to a farmer field school and 13 percent of the households had a member

[5] Twigire Muhinzi/Mworozi National Extension System is the government's homegrown, decentralized and farmer-oriented national system based on two complementary types of farmer-to-farmer extension approaches that include farmer promoters and farmer field schools (Neza et al. 2021).

who was an active member in agricultural cooperatives. Twenty-nine percent of the households accessed fertilizer and seed through Smart Nkunganire System[6] (SNS) demonstrating a somewhat lower level of overall participation and suggesting the need for increased participation in these programs. Overall, however, most households had access to extension services.

Sampled households were characterized by relatively small landholdings (average 0.35 ha per household). In terms of crop diversity, farmers had an average of 3.8 crop types with only half (1.9) being marketed. In terms of crop production, the household average sold value was 33 percent of production.

Livestock ownership was represented by an average of 0.6 TLU per household. In general, the average household profitability was characterized by a slightly negative agricultural return (slightly less than zero). Farmers produce relatively larger crop values but two-thirds is kept for home consumption and only an average of one-third is used to generate market revenue. Incorporating own consumption into value produced indicates a positive implicit crop and livestock gross margin[7] implying that positive economic value is created by most farm households. In other words, a large majority of agricultural households have total crop and livestock values greater than costs incurred.

[6] Smart Nkunganire System (SNS) is a system that enables Rwanda farmer self-registration capability to allow the application for subsidized agro-inputs on time using USSD short code via cellular phone technology. This process provides information related to farmer agro-input demand countrywide, the estimated cultivated land size, the agro-input distribution shops, and the estimated yield in the previous agriculture season.

[7] Careful attention must be given to definitional issues regarding a household's economic returns. We define explicit economic returns as gross margin, which is the total market sales minus variable production costs. This value captures the household's market interactions but is not the complete story. A more comprehensive definition would include own use, including own consumption and other uses, as well as implicit family labor costs and input subsidies. While this broader analysis suggests more positive benefits for the farm household, we chose to focus on market sales and costs that reflect actual market commercialization.

Table 1: Farmers' socio-economic and demographic characteristics description

Human Domain		Productivity domain	
Variable	**All farmers (n=2,020)**	**Variable**	**All farmers (n=2,020)**
Household size (adult equivalent)	4.4 (4.0)	Total landholding (Ha)	0.35
Household head is widow/widower (%)	20	Household produced cash crop (%)	9
Household head is female (%)	30	Number of all crops produced	3.8
Household head's age	48.5	Number of marketed crops	1.9
Household head is young (34 years old and less) (%)	21	Tropical Livestock Unit (TLU)	0.6
Household head is literate (%)	66		
Environment Domain		**Economic Domain**	
Inorganic fertilizers use (%)	48	Crop produce value (USD)	189
Pesticide/Fungicide use (%)	16	Household agricultural return (USD)	-8.6
Access to extension services (%)	72	Crop produce kept for home consumption value (USD)	54.5
Belong to Twigire Muhinzi/Mworozi (%)	6	Percentage value sold (%)	33
Belong to farmer field school (%)	8	Total fertilizer and pesticide cost (USD)	32.8
Current member of cooperative (%)	13	Implicit Gross Margin (USD)	110
Access to fertilizer and seed through SNS (%)	29	Household hired in labor (%)	48
		Household accessed wage income (%)	62
		Household have accessed to off farm income (%)	87

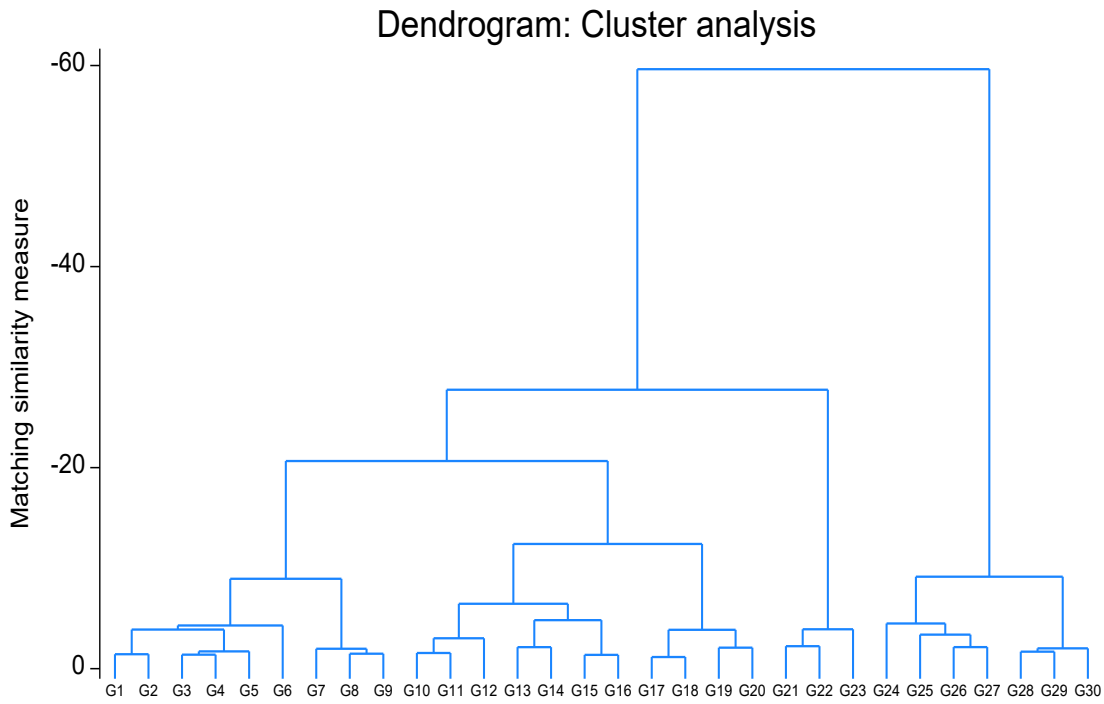
Source: Authors' calculations.

4.3 Farm typology

1. Farm typology identification

The results from III.2 provide a list of factors to be used in the cluster analysis. The following uses a hierarchical clustering method by applying Ward's linkage (Annex 2 provides an example). Figure 1 shows the outputted dendrogram demonstrating how the households in our sample can be allocated into different groups (or types) based on selected variables.

Figure 1: Dendrogram defining clusters

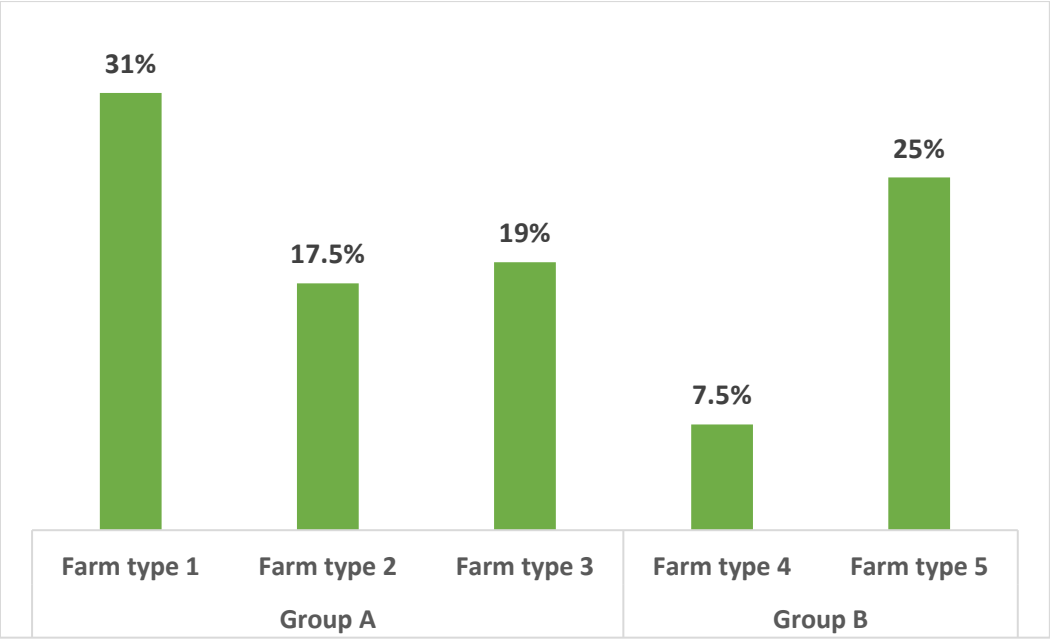


Source: Authors' calculations.

The horizontal axis(x-axis) represents the clusters. The vertical axis (y-axis) is a measure of the continuous similarity (closeness of either individual data points or clusters). Each joining (fusion) of two clusters is represented on the diagram by the splitting of a vertical line into two vertical lines. The vertical position of the split, shown by a short bar gives the distance (similarity). The similarity measure is the Euclidean distance[8] applied between two clusters to measure the degree to which the two objects are similar. Similarity is higher for more comparable pairs of objects with smaller Euclidean differences.

[8] The Euclidean distance between two points in the Euclidean space is defined as the length of the line segment between two points.

Figure 2: Farmer distribution across farm types



Source: Authors' calculations.

This starts at the bottom (= 0) as each observation is maximally similar to itself, and then forms clusters by increasing heterogenous observations with decreasing similarities (Nielsen 2016, Everitt, Landau and Leese 2001, Everitt 1993). There are two distinctly different places where we can cut the tree following the similarity measure. The dendrogram suggests different numbers of clusters, ranging from 2 to 6 starting from the matching similarity above -10. To validate the exact number of clusters to use, silhouette width was highest for 5 clusters. Therefore, five farm types were created and identified. After careful categorization based on shared characteristics, we have identified them into two distinct groups: Group A comprises Farm types 1, 2, and 3, while Group B consists of Farm types 4 and Figure 2 depicts the number of farmers across each farm type. Farm type 1 has the largest distribution of farmers and includes 627 of the sampled households, type 2 includes 353, type 3 accounts for 379 farm households, type 4, with the smallest distribution, accounts for 151 farmers, and type 5 is composed of 25 percent of our total sample representing 510 farm households. Farm types were defined using the variables accounting for most of the data variation between the farm types and relative similarity within the farm types. Tables 2 through 5 depict the general statistical relation between the five farm types using t-tests and serve as the basis for Table 6 and its farm typology summary.

2. Farm typology characteristics

Human Domain

In this category shortlisted variables, derived from our CA analysis, include adult equivalent, marital status, sex, age, maturity, and literacy of the household head.

Table 2. Distribution of characteristics by type in the social-human domain

Variable	Farm type 1	Farm type 2	Farm type 3	Farm type 4	Farm type 5
Adult Equivalent	4.75***	3.09***	2.56***	4.51***	4.71***
	[1.80]	[0.94]	[1.46]	[1.63]	[1.91]
Household head is widow/widower (%)	1***	1***	84***	14*	9***
	[0.10]	[0.08]	[0.36]	[0.35]	[0.28]
HH head is female (%)	15***	15***	94***	23**	15***
	[0.35]	[0.36]	[0.24]	[0.42]	[0.36]
HH head's age	48.7	28.63***	64.21***	46.93	50.95***
	[11.19]	[3.76]	[13.26]	[11.78]	[13.41]
HH head is young (34 years old and less) (%)	0***	100***	1***	13***	9***
	[0.00]	[0.00]	[0.09]	[0.33]	[0.29]
HH head is literate (%)	67	83***	27***	79***	81***
	[0.47]	[0.38]	[0.44]	[0.41]	[0.39]
Observation	627	353	379	151	510

Source: Authors' calculations.
Note: HH: Household; Standard deviations in brackets; * significant at 10%; ** 5%; *** 1%.

Table 2 demonstrates that most of the farm households in farm type 1 are married, 15 percent are female headed and all the household heads are above 35 years old. Farm type 2 is composed of young, educated household heads with only 15 percent being female-headed. Furthermore, the results indicate that households in Farm type 3 are older female headed households, predominately widowed, with lower literacy rates and a smaller household size. Farm type 4 and 5 are predominantly mature married male headed households with high levels of literacy.

Environment Domain

This category of variables includes inorganic fertilizers, pesticide/fungicide use, access to extension services, belonging to Twigire Muhinzi/Mworozi and farmer field schools, being a cooperative member and access to fertilizer and seed through SNS.

Table 3. Distribution of characteristics by type in the environment domain

Variable	Farm type 1	Farm type 2	Farm type 3	Farm type 4	Farm type 5
Inorganic fertilizers use (%)	33***	42**	24***	77***	81***
	[0.47]	[0.50]	[0.43]	[0.42]	[0.40]
Pesticide/Fungicide use (%)	6***	13*	4***	26***	37***
	[0.23]	[0.34]	[0.21]	[0.44]	[0.48]
Access to extension services (%)	68***	68**	60***	97***	85***
	[0.47]	[0.47]	[0.49]	[0.18]	[0.36]

Belong to farmer-to-farmer extension (%)	1***	2***	2***	42***	8*
	[0.11]	[0.15]	[0.12]	[0.50]	[0.27]
Belong to farmer field school (%)	1***	1***	1***	97***	0***
	[0.08]	[0.12]	[0.11]	[0.16]	[0.04]
Current member of cooperative (%)	5***	5***	5***	40***	29***
	[0.21]	[0.21]	[0.22]	[0.49]	[0.46]
Access to to Agro-Input subsidy through SNS (%)	21***	27	13***	51***	45***
	[0.40]	[0.44]	[0.34]	[0.50]	[0.50]
Observation	627	353	379	151	510

Source: Authors' calculations.
Note: HH: Household; Standard deviations in brackets; * significant at 10%; ** 5%; *** 1%

Table 3 depicts that farm type 1 had higher access to agro-Input subsidies through SNS, when compared to farm types 2 & 3 who have moderate access to extension services. Households in farm type 2, use more inorganic fertilizers, pesticide and fungicide when compared to farm types 1 & 3, who again exhibit less access to extension services. Farm type 3, predominately female headed households, are characterized by less use of inorganic fertilizers, pesticide, and fungicide coupled with low access to extension services and SNS program among all farm types. Group A-Farm types 1, 2 and 3, rarely belong to farmer-to-farmer extension (Twigire Muhinzi/Mworozi), farmer field school or cooperatives. Regarding farm type 4, most households had accessed extension services and participated in farmer field school compared to other farm types. Households in farm type 4 moderately use inorganic fertilizers and pesticide/fungicide. They also are more likely to use Agro-Input subsidies through SNS and were more likely to be a member of agricultural cooperatives and farmer-to- farmer extension (Twigire Muhinzi/Mworozi). Farm type 5 had higher use of inorganic fertilizers and pesticide/fungicide compared to all other farm types and were less likely to belong to Twigire Muhinzi/Mworozi national extension service, but they moderately used SNS agro-input subsidies.

Productivity domain

This domain comprises landholdings, crop production, crop marketing, and livestock holdings (measured in TLU).

Table 4. Distribution of characteristics by type in the productivity domain

Variable	Farm type 1	Farm type 2	Farm type 3	Farm type 4	Farm type 5
Total landholding	0.19***	0.15***	0.20***	0.47***	0.76***
	[0.21]	[0.24]	[0.27]	[0.58]	[0.88]
Household produced cash crop (%)	6***	3***	4***	17***	19***
	[0.23]	[0.17]	[0.21]	[0.37]	[0.39]
Number of all crops produced	3.37***	3.19***	3.26***	4.49***	5.05***
	[1.49]	[1.54]	[1.68]	[1.83]	[2.40]

Variable	Farm type 1	Farm type 2	Farm type 3	Farm type 4	Farm type 5
Number of marketed crops	1.15***	1.43***	1.35***	2.50***	3.28***
	[1.09]	[1.31]	[1.30]	[1.56]	[1.68]
Tropical Livestock Unit	0.52***	0.35***	0.37***	0.73	1.13***
	[0.60]	[0.48]	[0.50]	[0.74]	[1.36]
Observation	627	353	379	151	510

Source: Authors' calculations.
Note: HH: Household; Standard deviations in brackets; * significant at 10%; ** 5%; *** 1%

Table 4 highlights that farm type 1 is characterized by a greater number of crops produced but a smaller number of crops marketed within group A and far less than group B. In addition, farm type 1 has larger livestock holdings compared to farm types 2 and 3. Households in farm type 2 have smaller landholdings, lower livestock ownership and a smaller number of crops produced compared to all farm types. However, farm type 2 market more crop types within group A. Farm type 3 is characterized by larger landholding compared to farm types 1 & 2. Farm type 4 is characterized by larger land size, higher livestock ownership, and a greater number of produced crop types compared to all farm types in Group A.

Economic Domain

This category of variables is composed of crop production value, agricultural return (both crop & livestock), production kept for home consumption, percentage value sold, fertilizer and pesticide cost, hiring in labor, wealth index, and own access to wage income and off farm income.

Table 5. Distribution of characteristics by type in the economic domain

Variable *BNR Exchange rate- 2022 October average rate ---1,045.74*	Farm type 1	Farm type 2	Farm type 3	Farm type 4	Farm type 5
Crop produce value (USD)	87.44***	79.97***	79.00***	243.05**	455.10***
	[70.76]	[86.63]	[80.33]	[264.03]	[435.84]
Household agricultural return (USD)	-49.63***	-40.09**	-22.86	8.8	69.67***
	[197.95]	[121.69]	[106.15]	[252.87]	[546.91]
Crop produce kept for home consumption value (USD)	43.33***	27.86***	30.04***	68.23***	100.72***
	[40.22]	[25.50]	[27.16]	[54.29]	[99.33]
Percentage value sold (%)	22***	26***	26***	40***	55***
	[0.23]	[0.25]	[0.27]	[0.25]	[0.22]
Fertilizer and pesticide cost (USD)	17.33***	14.60***	16.28***	48.42***	72.08***
	[21.28]	[20.79]	[27.41]	[46.37]	[61.26]
Crop implicit gross margin (USD)	48.03***	38.83***	38.46***	136.12	281.18***
	[85.82]	[82.09]	[94.48]	[210.39]	[425.43]
Household hired in labor (%)	27***	39***	38***	64***	81***

Variable *BNR Exchange rate- 2022 October average rate ---1,045.74*	Farm type 1	Farm type 2	Farm type 3	Farm type 4	Farm type 5
	[0.45]	[0.49]	[0.49]	[0.48]	[0.39]
Wealth index	-0.44***	-0.53***	-1.36***	1.19***	1.57***
	[2.03]	[1.98]	[1.79]	[2.57]	[2.16]
Household accessed wage income (%)	79***	84***	47***	51***	42***
	[0.41]	[0.37]	[0.50]	[0.50]	[0.49]
Household accessed to off farm income (%)	90***	95***	88	79***	79***
	[0.30]	[0.21]	[0.32]	[0.41]	[0.41]
Observation	627	353	379	151	510

Source: Authors' calculations.
Note: HH: Household; Standard deviations in brackets; * significant at 10%; ** 5%; *** 1%

Table 5 demonstrates that farm type 1 is composed of less crop commercialized (percentage value sold) households with lower agricultural return and less use of hired labor among all farms. They also exhibit greater input costs (fertilizer and pesticide) as compared to farm types 2 and 3. This farm type has larger agriculture production value than others in group A, and more production kept for their own consumption. Finally, farm type 1 has higher gross margins and a great average wealth index compared to farm types 2 and 3 but not group B.

Farm type 2 households were characterized by lower crop produced value, lower gross margins, and a lower wealth index. Among all farm types, farm type 2 had lower crop production kept for own consumption, indicating greater relative commercialization. Farm type 2 also has lower fertilizer and pesticide cost, but higher access to off farm and wage income among all farm types. Farm type 4 and 5 had more positive and higher agricultural returns than all of group A.

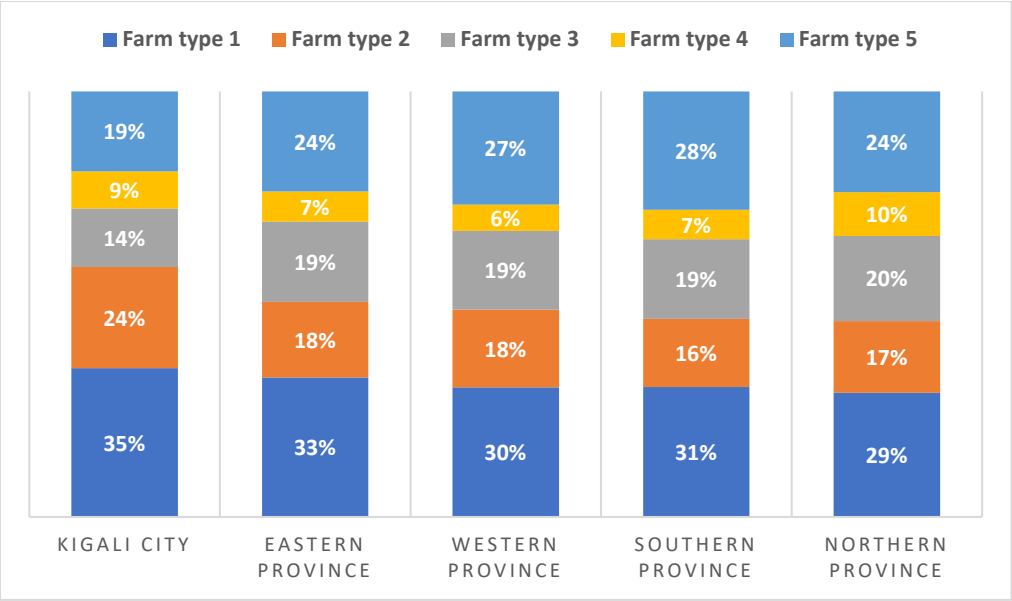
Farm type 4 households were highly commercialized and had higher crop production value, higher input costs, a higher wealth index, and more hired labor compared to all of group A. Households in farm type 5 are highly resource endowed and commercialized. They have higher crop production value, higher agricultural returns, and higher gross margins, a higher wealth index, higher proportion of hiring-in labor and higher overall input costs than all other farm types.

4.4 Distribution of farm types across selected socio-economic characteristics

Distribution of farm types across provinces

Figure 3 indicates that all farm types are relatively equally distributed across provinces, where farm type 1, the largest of all the five farm types, has about 30 percent total across all five provinces. The smallest farm type, farm type 2, has between six to ten percent of all sampled households across the provinces. Farm type 2 has a slightly higher proportion in Kigali city with 24 percent where the average is about 17 percent across all provinces. Overall, this distribution suggests that potential initiatives targeting any of the farm types would likely have to occur in all provinces in the country.

Figure 3: Distribution of Typologies within different Provinces

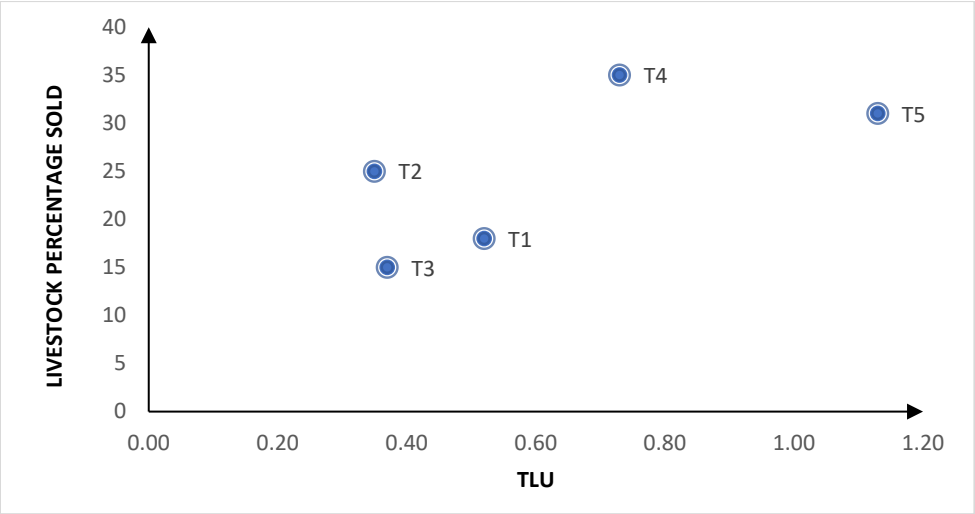


Source: Authors' calculations.
Note: Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

Distribution of commercialization categories across farm types.

Differentiating farm types based on their agricultural commercialization categories can be a complex task as it depends on various factors such as the crops grown, livestock raised, production scale, market orientation, and other economic activities. One such measurement that identifies commercialization is the level of crops and livestock sold at the household level. Figure 4 identifies the extent to which the five farm types of market their livestock relative to the amount of livestock holdings, measured in TLU.

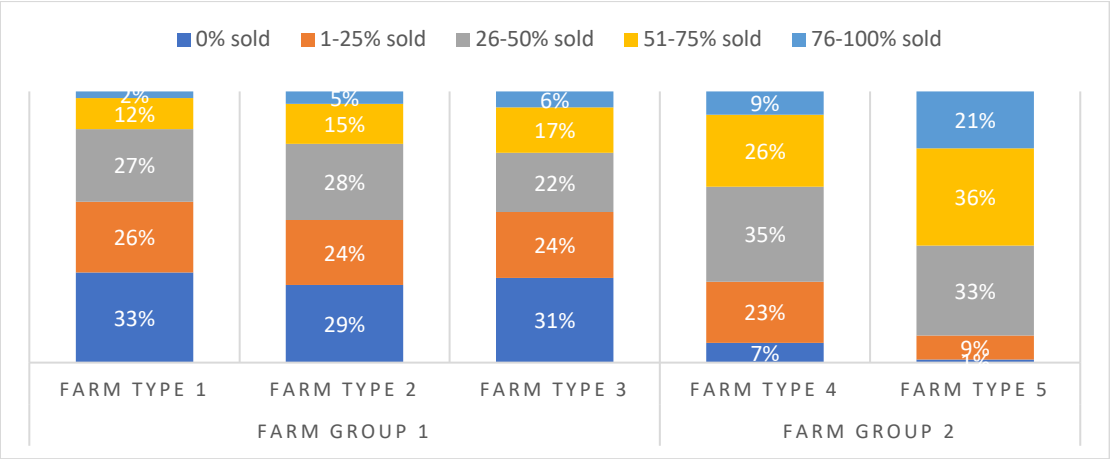
Figure 4: Distribution of livestock commercialization proxy across farm types



Source: Authors' calculations.
Note: Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

Livestock are a valuable asset that can generate income from multiple sources, such as meat, milk, eggs, honey, and leather. However, livestock also require significant resources to raise and keep, and costs include feed, water, land, and veterinary care. By diversifying their livestock portfolio and selling a higher proportion of their animals, farmers can reduce their dependence on crops, increase their cash flow, and optimize their production efficiency. Figure 4 demonstrates that across all farms, farm type 4 sold a greater percentage of livestock and their products. Households in farm type 5 had the highest amount of livestock (TLU) but compared to those in farm type 4, they are less commercialized due to a lower percentage of livestock sold. Farm type 2 has a higher percentage of sold livestock products compared to farm type 1 and 3, although farm types 1 and 2 had a higher TLU, which implies that farm type 2 is more commercialized than others in group A. Selling a greater percentage of livestock holdings, across all farm types, is a crucial strategy for farmers to diversify income sources as well as a strategy to mitigate crop risks. This study also reveals that, on average, more than half of households did not sell any livestock products (52 percent) while in crop production only 22 percent did not sell any crops. Drawing upon this result, this study primarily focuses on crop commercialization for income generation, demonstrated in Figure 5 below.

Figure 5: Distribution of Commercialization proxy category within farm types



Source: Authors' calculations,
Note:Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

The following discusses categorical crop commercialization and farm type:

1. **Subsistence Farmers (0 percent sold):**

Subsistence farms are primarily focused on producing food and other agricultural products for the farming household's own consumption, with a minimal engagement in crop selling. Based on our defined farm types, across all five types, subsistence farmers are equally distributed across farm group A, and rarely found in farm group B. These farmers often use traditional farming methods and have limited access to modern inputs and technologies which can be justified by the fact that more farmers in group A had less use of inorganic fertilizers, pesticides, and fungicides. They are also characterized by less access to extension services, and less access to fertilizer and seed through SNS, compared to farm type 4 and 5. While group A has about 30 percent of each farm type with no sales, this does not mean that subsistence farmers are a homogenous group and should be subject to similar intervention strategies. For example, farm type 2 is more educated and appears to be more amenable to crop marketing. Therefore, programs to increase the awareness and adoption of different technologies, such as the use of modern inputs, particularly among farm type 2, are important to make the identified farmers' categories increase their market commercialization.

2. **Smallholder farmers (1-25 percent sold):**

Smallholder farmers are slightly more commercialized than subsistence farms. They produce crops and livestock not only for family consumption but also for limited sale. Smallholder farmers may have limited resources and access to technology but aim to generate some income from agricultural activities. Farm type 1 to farm types 4 have more of these smallholder farmers (about 25 percent across all four categories percent respectively). Initiatives related to technologies and innovation are recommended for this group but particularly for farm types 2 and 4 to boost their crop commercialization percentages.

3. **Market-Oriented Farmers (26-50 percent sold)**

Somewhat market-oriented farmers are primarily focused on producing crops and livestock for consumption but also sell a significant amount of their crops for sale. These farmers often use more modern agricultural practices and technologies. The primary goal of market-oriented farms is to generate a significant portion of their income from agricultural sales and is the most common category across all farm types, representing between 22 and 35 percent of all categories. Farm type 2 had slightly more market-oriented farmers (28 percent) compared to farm type 1 and 3, while farm type 4 and 5 had more market-oriented farmers compared to all other farm types. Market oriented farmers need more initiatives and programs to strengthen the use and availability of modern agricultural practices and technologies to increase their production and income. This is in line with identified characteristics of farm types 4 and 5 who have higher access to improved inputs and extension services across all farm types. Finally, most of them participated either in cooperatives, farmer field schools or the Twigire Muhinzi/Mworozi program.

4. **Commercial Farmers (51-75 percent sold):**

Commercial farmers are characterized by their strong emphasis on agricultural crop sales. Farm types 4 and 5 have a greater number of these commercial farmers. Farm type 5 has the highest number of commercial farmers (farmers who sold between 50 to 75 percent of their crop produce) across all farm types. This farm commercialization category demonstrated that more commercial farmers (farm type 4 and 5) often operate on a larger land scale, but not exclusively on large land holdings. This grouping use more modern inputs while accessing information and extension services, to increase their adoption of advanced technologies and practices to maximize production and profit. Advancing specialization in specific market crops or livestock is crucial to advancing their level of commercialization.

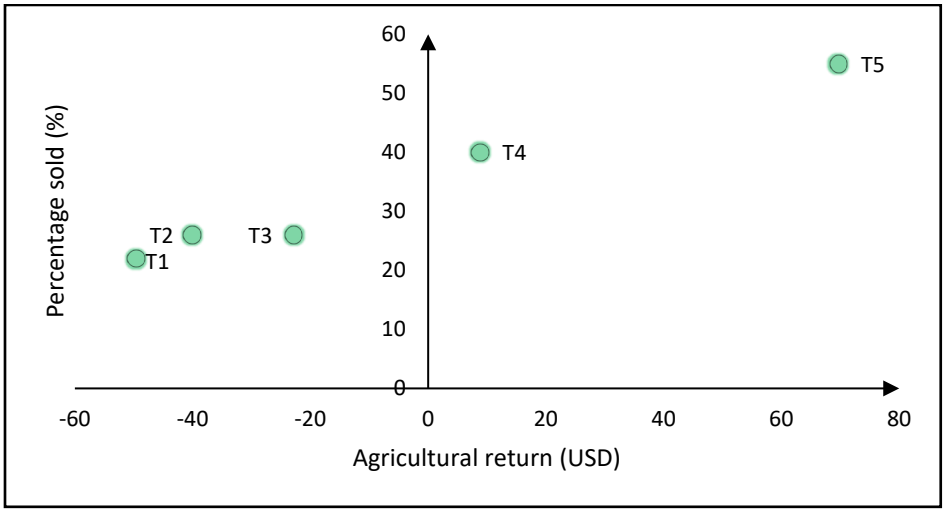
5. **Agribusiness Entrepreneurs farmers (76-100 percent sold):**

Agribusiness enterprises encompass commercial farming operations and are often integrated with other value chain activities such as processing, distribution, and marketing. These farms and businesses are highly commercialized, with a focus on profit generation and supply chain management. They have significant access to capital, technology, and markets. Farm type 5 has a great number (21 percent) of those farmers compared to others farm types and this can be explained by their high agricultural return and wealth index. Therefore, effort is needed to increase the number of farmers into this level of commercialization for greater income and welfare. Importantly, this category is not exclusively based on land size, which suggests that besides land holdings, farm types, such as farm type 2, might be more amenable to these types of intervention strategies. Overall, it is important to keep in mind that these categories are not permanent, and there can be variations within each farm type. Farms may transition from one category to another over time as they adapt to changing market conditions, such as technology adoption, crop choice, as well as other factors. Additionally, local and regional variations can influence the degree of commercialization among farms in different areas which calls for more advanced studies to explore this in more detail.

Distribution of Typologies by percentage value sold crops and agricultural return.

Figure 6 graphically depicts that farm type 1 to 3 have lower percentage crop sold and negative agricultural return with farm type 3 having less negative agricultural return (-23 USD) compared to farm types 1 and 2 (-40 and -50 USD respectively). This suggests that production costs exceed marketed production revenue for farm type 2, but at a smaller financial loss than farm type 1 and 2. There are several possible explanations including: rising costs of production (inputs, labor, land and rent costs), weather and climate conditions, market prices, economic conditions, technologies and efficiency, government policies and market access. This is justified by the fact that farm types 1 to 3 are characterized by high costs of inputs such as seeds, fertilizers, and pesticides that may have significantly impacted their production expenses. In addition, farmers in type 2 have smaller landholdings compared to other farm types. Increasing their costs are the added expenditures of land rental and hired labor compared to farm types 1 and 3. Most importantly, farm group A directly consumes a large amount of production which creates a negative rate of return.

Figure 6: Distribution of typologies by percentage value sold crops and agricultural return.



Source: Authors' calculations
Note: Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

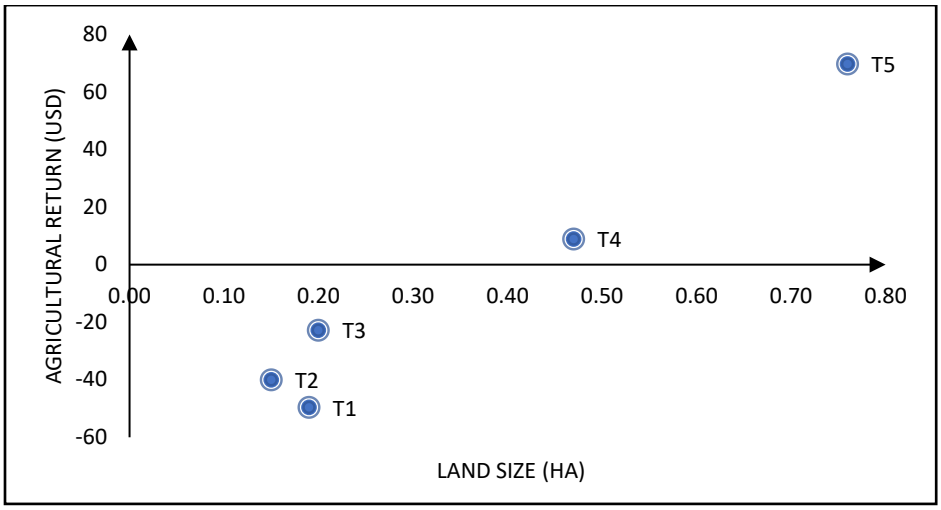
In terms of technology and efficiency, farm group A has lower access to extension services and lower use of improved inputs and less participation in agricultural information and extension groups like cooperatives, farmer field school and Twigire Muhinzi/Mworozi, when compared to farm group B. While farm group A has the disadvantage of lower crop sales and negative agricultural returns compared to farm group B, farm type 1, has a greater own labor pool to draw from for more labor-intensive activities.

From an income perspective, interventions could be designed to better focus production on higher-valued commercial crops over crops to feed the larger family. Better engagement by extension services and participation in cooperatives could also help this farm type. Other potential activities include off-farm businesses and higher-paying wage labor activities.

Distribution of Typologies by land size and agricultural return

Figure 7 illustrates agricultural return and land size across the five identified farm types. Farm types in group A have relatively smaller farm sizes compared to group B, with farm type 2 having the smallest average farm size of all farm types. A strong positive relationship between farm size and agricultural returns exists across all five farm types. Overall, farm type 5 has approximately five times the average landholdings compared to farm type 2. This is critical for intervention design, because farm size is tied to absolute income returns even though relative returns per hectare need to also be considered for efficiency reasons.

Figure 7: Distribution of Typologies by land size and agricultural return



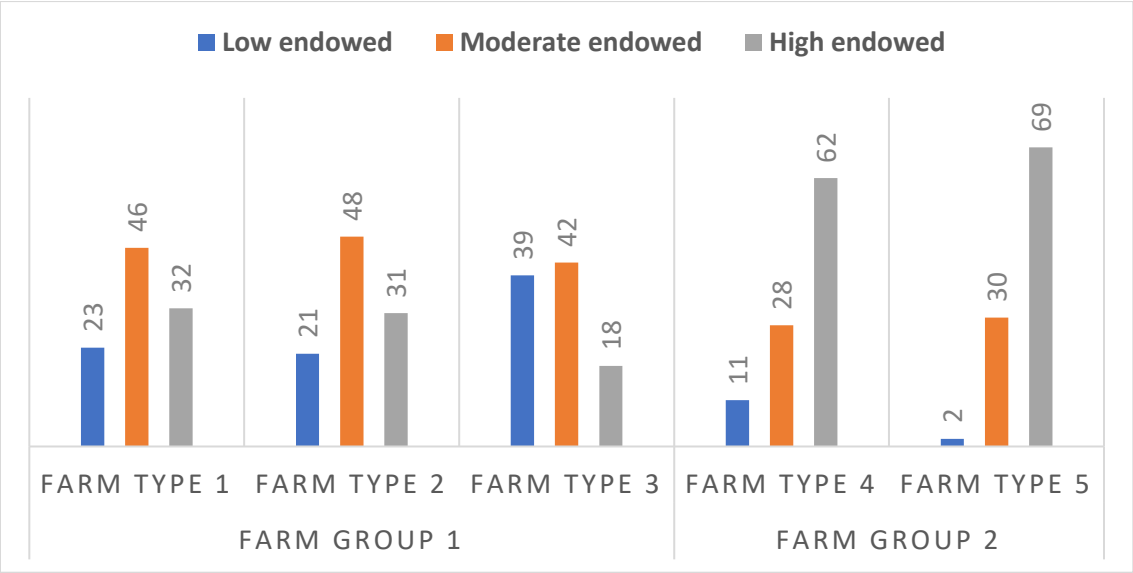
Source: Authors' calculations,
Note:Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

Figure 7 illustrates that agricultural returns do not necessarily depend solely on the size of the land. The results indicate that farm type 2 has higher agricultural returns than farm type 1 even though farm type 2 has less land holdings. Also, it is important to note that farm type 4 has significantly less land than farm type 5 even though both have positive rates of return and are more crop commercialized than all of group A. Many other factors, including crop selection, management practices, soil quality, climate, access to resources, market conditions, and government policies, interact with land size to influence agricultural outcomes. Successful farming often involves optimizing all these factors rather than focusing solely on the size of the land. Therefore, government policies, subsidies, and incentives can have a significant impact on agricultural returns. Support for small-scale farmers or certain crops can level the playing field for smaller landholdings.

Distribution of wealth endowment categories within farm types

We defined lower-endowed households as the ones in the bottom quartile of the wealth distribution, mid-endowed households as the ones in the 2nd and 3rd quartile and highly endowed households as those in the top quartile of the asset distribution. Figure 8 depicts which of the endowment's category fall most of the households in our typologies.

Figure 8: Distribution of Typologies by endowment index

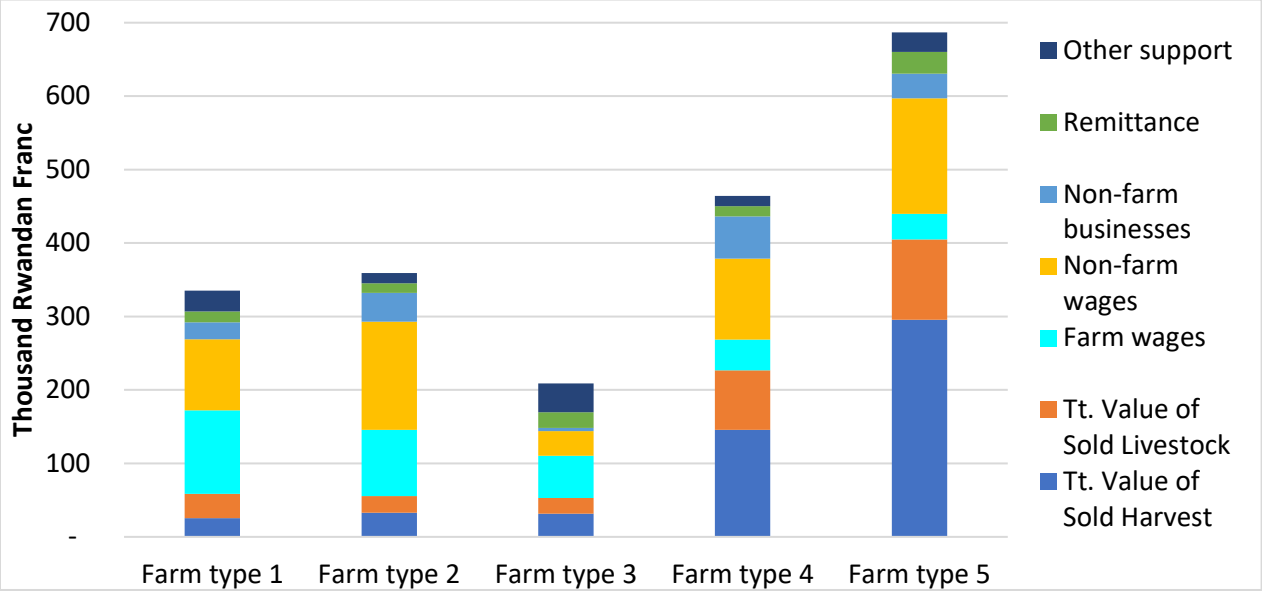


Source: Authors' calculations
Note:Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

Figure 8 illustrates that farm group A is more moderately endowed, with farm type 3 representing the lowest of the three farm types in terms of wealth endowment farmers. Farm types 4 and 5, have relatively higher endowed farmers and from Graphs 6 and 7, those farms also have higher agricultural return and larger land size. This implies that wealthy farmers may have the resources to invest in modern agricultural technology, be able to better manage agricultural risks and have access to capital. This access to resources will enable them to afford to purchase high-quality seeds, fertilizers, pesticides, and other inputs and can lead to higher agricultural returns through the use of modern agriculture practices, improved inputs, irrigation systems, and digital farming techniques, which can increase productivity and reduce production costs what is justified by characteristics of farmers in type 4 and 5 (Table 6). Promoting policies to support wealth creation among farmers is essential for sustainable agriculture and rural development. Wealthy farmers can invest in modernizing their farms, adopting sustainable practices, and contributing to the overall economic growth of their communities.

Sources and amounts of income by farm types

Figure 9 Sources of income by farm type



Source: Authors' calculations.
Note: Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

Figure 9 depicts the relative sources and amounts of income generated at the household level by farm type. This graph is helps contextualize the importance of current incomes sources and how they vary. The value of sold harvest are similar across all of group A but other sources vary significantly. Perhaps most importantly crop income is not the majority source of income for all of group A. In this group, the predominant form of income comes from non-farm and farm wage labor. However, this should be contextualized within the total value of sold harvest. Group A consumes a large amount of its' crop production, which is important for feeding the household members, even if it is not marketized by sales.

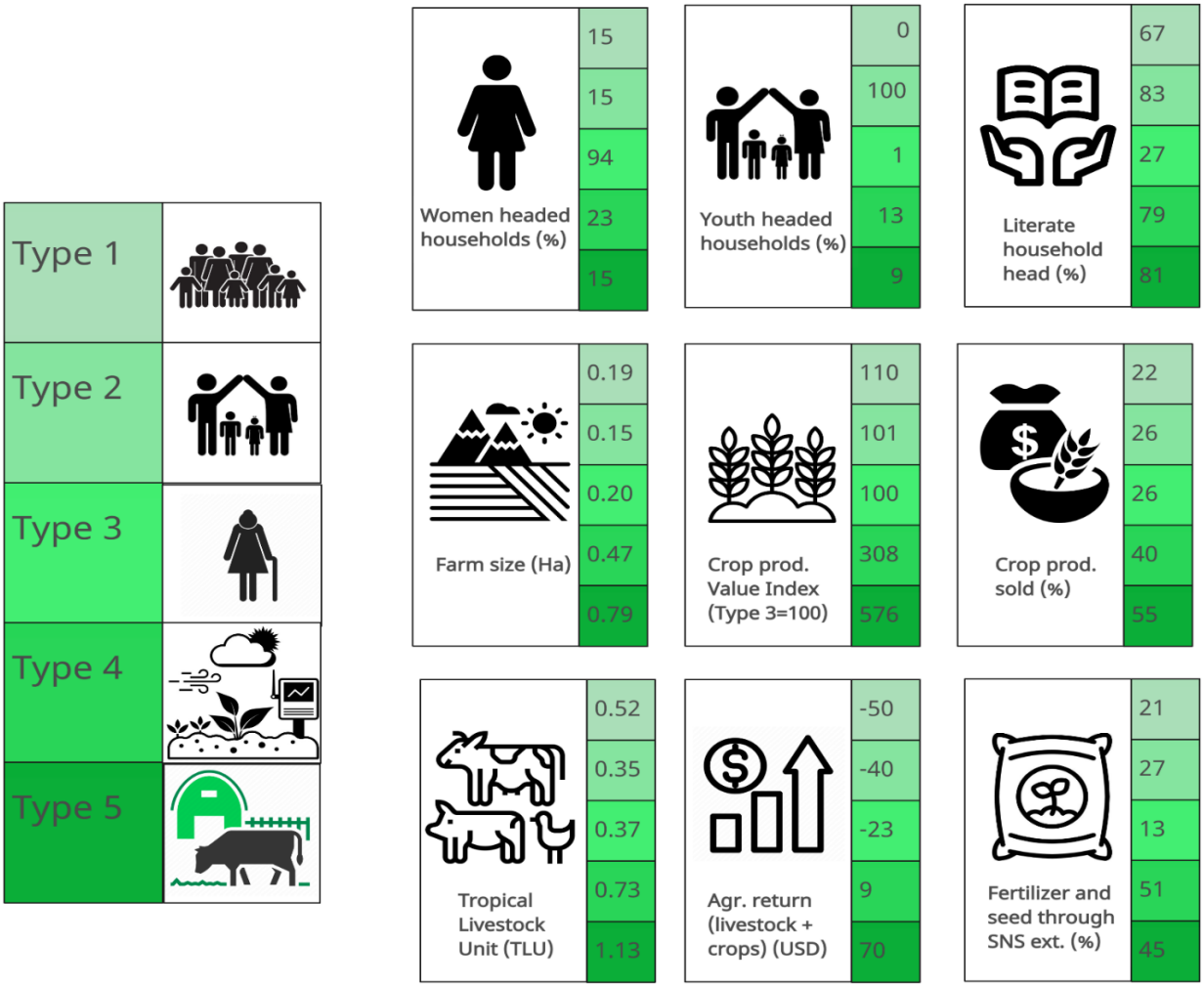
While farm type 3 has similar crop income compared to farm types 1 and 2, other income sources are far less important. This suggests that farm type 3 is not as active in other sources of income and relies more heavily on crop sales for money. Farm type 2, primarily youth-headed households, are more active in labor and non-farm businesses. In terms of total income, farm type 5 is larger than all other farm types and dominates in almost all income categories. This farm type generates nearly twice the overall household average income and is nearly three times greater than farm type 3.

Graph 9 makes the important point that the typical household does not merely rely on crop sales, and even to a lesser extent livestock, but have at least five sources of income. This is important for policy because merely focusing on crop production or productivity may miss other important sources of income for the household.

5. GENERAL STATISTICAL OVERVIEW OF THE FIVE FARM TYPES

Figure 10 provides a general statistical overview of the five farm types or typologies. It is meant to give a brief quantitative review of the entire discussion above.

Figure 10: General statistics by farm type



Source: Authors' calculations.
Note: Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

FARM TYPOLOGY SUMMARY

Figure 11: General Farm Typologies summary (2 groups, 5 types)

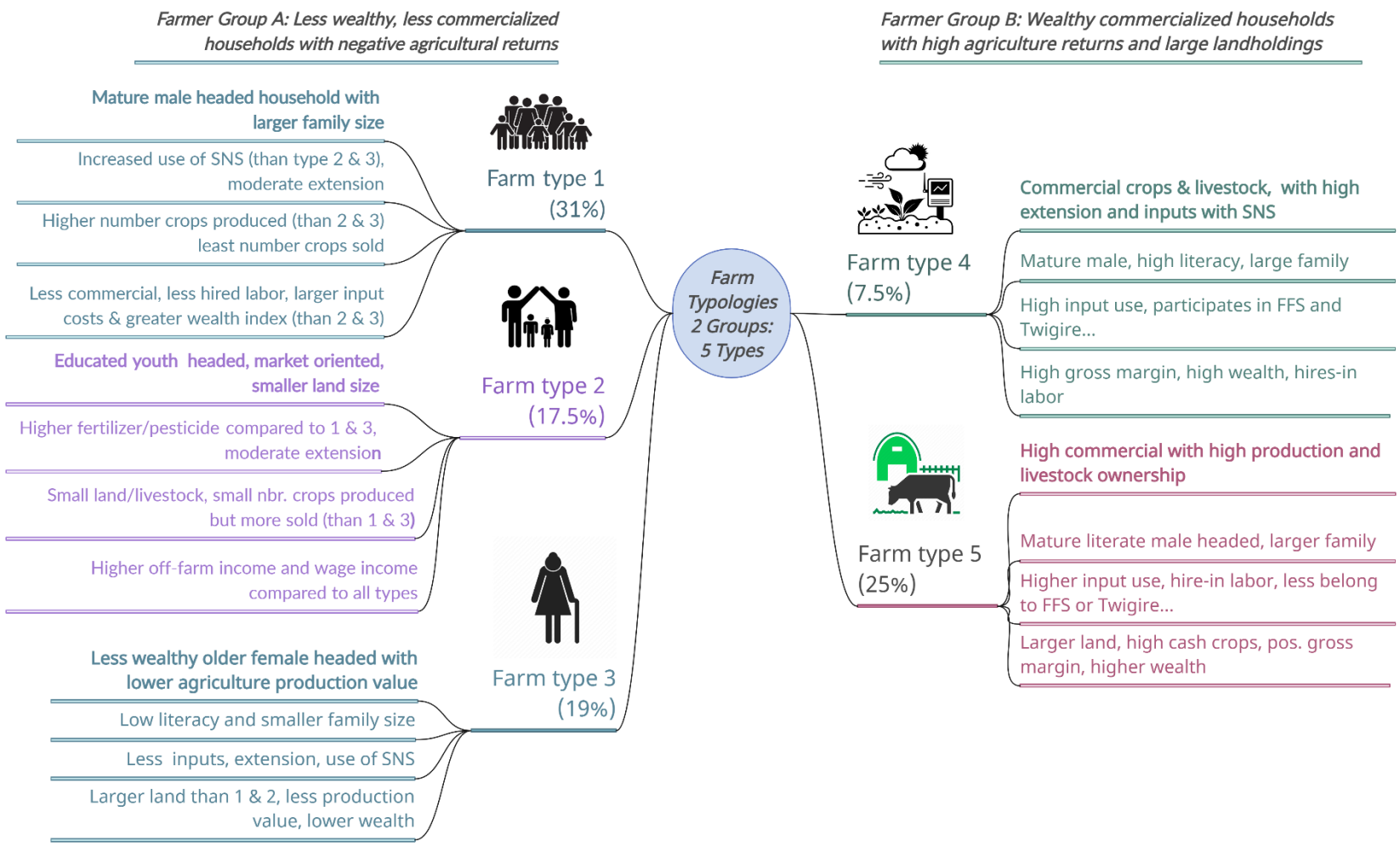


Table 6: Farm typology summary

Farm typology		Human Domain	Environment Domain	Productivity domain	Economic Domain
Farmer Group A: Less wealthy and less commercialized households with negative agricultural returns	***Farm type 1: Less commercialized mature male headed households with the highest family size***	Mature male headed household. Higher family size (adult equivalent) among all farm types.	Higher access to fertilizer and seed through SNS compared to farm types 2 & 3 with moderate access to extension services.	High number of crops produced. Higher livestock holdings compared to farm types 2 & 3. Less number of marketed crops among all farm types.	Less commercialized (% sold) households with lower agricultural return coupled with less use of hired labor among all farms. Larger input cost (fertilizer and pesticide) compared to farm types 2 & 3. Large agriculture production value but higher production kept for consumption, higher gross margin and wealth index compared to farm 2&3.
	Farm type 2: Educated youth headed, market-oriented households with smaller land size.	Younger headed households. Highly levels of literacy among all farm types.	Higher use of inorganic fertilizers, pesticide and fungicide compared to farm 1&3. Moderate access to extension services.	Smaller landholding and lower livestock with a smaller number of crops produced compared to all farm types. More marketed crops compared to farm types 1 & 3.	Lower production kept for consumption. Low fertilizer and pesticide costs. Higher off farm income and wage income among all farm types.
	Farm type 3: Less wealthy older female headed household with low agricultural production value	Widow older female headed household. Low levels of literacy and adult equivalent among all farm types.	Less use of inorganic fertilizers, pesticide and fungicide. Less access to extension services. Less accesses to fertilizer and seed through SNS extension among all farm types.	Relatively larger landholdings compared to farm types 1 & 2 but not group B.	Less crop production value. Lower gross margin. Lower wealth index.
Farmer Group B: Wealthy commercialized households with high agriculture returns and large landholdings.	***Farm type 4: Highly commercialized households -in livestock with high access to extension services and to Agro-Input subsidy***	Mature literate male headed household.	High access to extension services. Belongs to Twigire Muhinzi/Mworozi and farmer field school/ member of cooperatives. High accesses to fertilizer and seed through SNS extension.	Relatively larger land size. Produced more cash crops. Higher livestock holdings, a greater number of produced and marketed crops (compared to farm group A).	Highly commercialized especially in livestock production. Higher crop production value. Higher input cost. High wealth index. Hired-in labor (compared to Group A).
	Farm type 5: Highly commercialized - in crop households with high agricultural production and livestock.	Mature male headed household. High levels of literacy and larger household size (adult equivalent).	High use of inorganic fertilizers, pesticide, and fungicide. Did not belong to farmer field school with less/insignificant participation in Twigire Muhinzi/Mworozi	Large landholdings. High tropical livestock unit among all farm types. High number of cash and marketed crops among all farm types.	Highly commercialized in crop production. Higher crop production value. Higher agricultural return. Higher input cost. Higher gross margin. Higher wealth index does not engage in wage income. Higher hired-in labor (among all farm types).

6. CONCLUSION

This research provides five commercialization-based analytical categories of Rwandan farm households that move beyond previous designations of subsistence and commercialized farmers. The goal is to provide a more nuanced understanding of how different groups of farmers interact with markets and undertake market activities. Grouping agricultural households into meaningfully different analytical categories can better inform policymakers on potential responses to interventions and improve efficient uptake.

This paper derived the typologies based on a variety of statistical methodologies, most notably cluster analysis (CA), to create these five farm types. By grouping smallholder farmers into types, or typologies, based on common characteristics that are both consistent within these groups and relatively dissimilar outside each group we determine a set of five types of Rwandan agricultural households, in two broad groups. The first group includes three types of farming households and are generally classified as less wealthy, less commercialized, with a net negative gross crop marketing margin. Group A includes farm type 1, less commercialized older male headed households with larger families, type 2 households are more educated, youth headed households, with a predisposition towards commercial activities but with the smallest average land holdings. Type 3 are older female headed households who produce lower agricultural production value and are not as engaged in other income generating activities.

The second group, group B, is comprised of two types (type 4 & type 5) and represents about one-third of all farm households. This group are wealthier, more commercialized households, with positive gross marketing margins and larger landholdings. Farm type 4 is highly commercialized especially in livestock with higher access to agricultural extension services and inputs. Farm type 5 is also highly commercialized in both crops and livestock but have augmented their crop production with significant livestock holdings. Taken together, these two groups, and five farm types, provide a better understanding of how commercialization is undertaken in Rwandan agriculture.

These typologies are designed by determining statistical relationships between the five farm types but are certainly not the only methodology that could be used for grouping farm households. An obvious idea would be to cluster farmers by the level of current crop sales. However, as depicted in Figure. 5, the current actual level of sales may not capture the most salient aspects of potential commercialization. While approximately 30 percent of all households in group A do not sell any crops, it is likely that they would respond to targeted interventions differently. For example, farm type 2 is younger, better educated and tends to use more inputs than the others in group A (farm types 1 and 3) and likely to respond more positively to targeted SMS interventions. This stands in contrast to farm type 3, predominately older women, who would likely be less technologically oriented. While percentage crop sales may appear like a good idea for depicting farmer behavior, we believe the methodology used captures important differences between groups for improved targeting and policymaking. The next section provides some recommendations at the farm type level.

7. RECOMMENDATIONS

Improved identification of how Rwandan farmers engage in crop marketing is critical for more efficient and effective policymaking. This research posits that multiple farm types, or typologies, exist, each having significant commonalities within each grouping and important differences between groups. Moving beyond simplistic designations, like subsistence and commercial, policymakers could better target expected outcomes via responses ascertained from the identified

farmer types. Importantly, each farm type might respond differently to a particular agricultural intervention and policymakers would better understand how and why that would be the case.

Policies to support less commercialized households, identified in group A, are important for ensuring improved food security and potential welfare gains, via either greater productivity of the crops they are currently producing or by creating the opportunity for producing more valuable crops. Overall, interventions should be tailored to the specific needs and circumstances of the local agricultural community as well as characteristics of the designated farm type. Primarily less commercialized farmers center on our designated group A, or three farm types (farm type 1, 2, and 3). Despite some commonalities, these three types also have important differences which could matter for policy interventions. In addition, strategies to support group B, farm types 4 and 5, the more commercially successful farmers, are crucial for ensuring broader economic growth, and rural development.

An example of how this research can be used is derived from Figure 9. Figure 9 depicts that group A households, particularly farm types 1 and 2, receive between two and three times as much farm wage income than group B and is evident that group B hires in farm labor while group A are hiring out. Data reveals that farm types 1 and 2 are five times less likely to hire in wage labor about 3.5 times less likely to hire out labor only, indicating the importance of wage labor benefits for group A and costs for group B. Using the typologies framework, more productive farms, in group B, could increase group A's marginal income in the form of higher wages, particularly farm types 1 and 2. A strategy of targeted group B growth and management of wage labor markets, could improve all farm households via a virtuous cycle of agricultural growth and rising farm wages. This interrelationship between group A and group B, especially via wage labor engagement, has not received a great deal of research attention but may be important for creating synergies of growth and income distribution in the agricultural sector.

While farm types 4 and 5 are already performing better across all the aspects related to wealth and commercialization, supporting group B could facilitate increased production, higher technical efficiencies and close the agricultural productivity gap between current and optimal yields. In addition, policies to support these more commercialized farmers could improve agricultural growth and accelerate the economic transformation. Therefore, a comprehensive and holistic approach that addresses varying aspects of all farm typologies could be most effective in promoting production, food security, income, and welfare. While policies should likely vary by region and typology, the following recommendations offer potential strategies and policies by the identified farm types.

6.1 Recommendations for farm type 1

Farm type 1 is composed of older male headed households with larger families and smaller landholdings, when contrasted to group B. They are less commercially oriented because most of their production is consumed directly by the household. Based on the identified characteristics of typology 1, we suggest the following: An integrated intervention from government and other stakeholders supporting a rise in productive capacity, particularly among food crops. This could directly ease consumed food needs, create surplus production and promote commercialization, either by selling surplus or by adjusting to more valuable cash crops.

- **Targeted Capacity Building and Training**
  - **Agroecological training initiatives:** Implementing agroecological training programs tailored to Rwanda's farming system can educate smallholder farmers on sustainable practices like agroforestry, conservation agriculture, and integrated pest management. These programs would focus on techniques suitable for Rwanda's diverse agroecological zones, helping farmers maximize yields with minimal external inputs. Training programs and

demonstration plots would showcase these practices, empowering farmers to adopt sustainable and resilient farming methods.

- **Agripreunership training:** Offering capacity building initiatives and training programs focused on entrepreneurship, business management, and financial literacy can empower them to explore alternative livelihood options, diversify income sources, and make informed decisions about their farming operations and household finances. Training in market analysis, value addition, and quality standards can enhance their market participation and competitiveness.
- **Training and extension services expansion:** Providing targeted agricultural training and extension services to these large family households can equip them with the knowledge and skills needed to adopt improved farming practices, increase yields, and optimize resource use. Training programs may cover topics such as crop management, soil conservation, water management, pest and disease control, and post-harvest handling.

- **Farming Systems**
  - **Integrated farming systems**: Promoting integrated farming systems that maximize the use of available resources, such as crop residues, livestock manure, and organic materials, can enhance soil fertility and productivity without relying heavily on external inputs. These systems may include crop-livestock integration, agroforestry, and aquaculture, allowing households to diversify their income sources and improve food security.
  - **Agroforestry and perennial cropping systems:** Promoting agroforestry and perennial cropping systems that integrate trees, shrubs, and perennial crops with annual crops can improve land productivity, biodiversity, and resilience to climate change. These systems provide multiple benefits, including improved soil structure, microclimate regulation, and additional sources of income from non-timber forest products**.**
  - **Enforcing terracing and soil conservation projects:** Investing in terracing and soil conservation projects specific to Rwanda's hilly terrain can mitigate soil erosion and improve soil fertility. By implementing these practices, farmers can sustainably manage their land, increase agricultural productivity, and protect against soil degradation, which is crucial in a country with limited arable land.
- **Access to Agricultural Inputs and Technology**
  - **Targeted subsidy programs:** Facilitating access to agricultural inputs such as seeds, fertilizers, pesticides, and machinery through targeted subsidy programs, input vouchers, or group procurement arrangements can help households with smaller landholdings overcome financial constraints and increase their agricultural productivity.
  - **Adoption of technologies:** Promoting the adoption of appropriate agricultural technologies and mechanization solutions suited to small-scale farming can further enhance efficiency and productivity.
  - **Community-based seed banks:** Establishing community-based seed banks to ensure access to locally adapted and resilient crop varieties. These seed banks would collect, preserve, and distribute seeds, including traditional varieties, suitable for Rwanda's agroecological conditions, reducing farmers' reliance on costly external seed sources.

    Policy support and incentives: Providing policy support and incentives, such as subsidies for organic inputs, tax breaks for agroecological practices, or preferential procurement policies for sustainably produced goods, can create an enabling environment for the adoption of sustainable farming methods by households with limited resources.

- **Access to finance and credit facilities:** Facilitating access to finance and credit facilities through tailored loan products, grants, or microfinance schemes can enable male-headed households to invest in agricultural inputs, equipment, and infrastructure. Financial products should be designed to accommodate the specific needs and circumstances of smallholder farmers, with flexible repayment terms and low-interest rates.

- **Market Access:**
  - **Market access and value chains:** Strengthening market linkages and value chains for agricultural products through market information systems, networking opportunities, and support for collective marketing arrangements (Strengthening their participation in farmer organizations and cooperatives) can enable access to markets and sell their produce at fair prices.
  - **Promotion of market premiums:** For example, market premiums for organic or agroecological products can enhance household income and livelihoods.
- **Infrastructure development:** Investing in rural infrastructure such as irrigation systems, farm-to-market roads, and storage facilities. This can reduce transportation costs, extend the shelf life of perishable crops, and enhance market access for farmers.
- **Diversification and income generation:** Promoting diversification of income sources and non-farm activities can reduce dependence on agriculture and enhance household resilience to economic shocks. This may include support for off-farm employment opportunities, entrepreneurship development, and income-generating activities such as agro-processing, livestock rearing, or rural tourism.
- **Social protection and safety nets:** Implementing social protection programs such as insurance schemes or safety nets can reduce risk and mitigate income fluctuations and market.

6.2 Recommendations for farm type 2

Farm type 2 is comprised of younger (under 35) farm households who are better educated and appear to have greater crop commercialization activities relative to their smaller land size. One of the main challenges facing the agricultural sector in developing countries is the low land assets and level of profitability of smallholder youth farmers. Therefore, our study results propose strategies to address this issue, to enhance the skills, knowledge, and access to extension services and encourage renting-in of land for these young farmers. Regarding the characteristics of farm type 2 these strategies and initiatives should aim to improve the quality and quantity of agricultural products, increase the income and livelihoods of rural youth, and promote better integration into value chains and agribusinesses.

Below are recommended initiatives for farm type 2.

- **Targeted Capacity Building and Training**
  - **Agricultural training and extension services**: Providing targeted agricultural training and extension services to youth farmers can equip them with the knowledge and skills needed to succeed in agriculture. Training programs may cover topics such as crop production techniques, soil management, pest and disease control, irrigation methods, and sustainable farming practices.
  - **Sustainable farming practices and financial sustainability:** Training programs that integrate financial literacy with sustainable farming practices help youth farmers understand the economic benefits of adopting environmentally friendly and resource-efficient farming methods. This includes cost-saving techniques, such as conservation tillage, organic farming,

and integrated pest management. Establish youth-led cooperatives and networks to enhance collective bargaining and learning.

- **Digital agriculture and agribusiness training:** Offering digital agriculture and agribusiness training programs that leverage technology and innovation can empower literate youth farmers to utilize modern tools and practices to improve productivity and efficiency. These programs may include training on farm management software, mobile applications for market access, precision agriculture technologies, and e-commerce platforms.
- **Agripreneurship incubators**: Establishing agripreneurship incubators or startup accelerators that provide training, mentorship, and access to resources and networks can support youth farmers in developing innovative agricultural business ideas and launching their ventures. These programs may offer support in business planning, market research, access to finance, and technical assistance.
- **Promotion of agri-tech and innovation hubs:** Promoting agri-tech and innovation hubs that serve as centers for research, development, and technology transfer in agriculture can foster a culture of innovation among literate youth farmers. These hubs may provide access to research facilities, prototype testing labs, mentorship programs, and collaboration opportunities with industry experts and academic institutions.
- **Risk management and insurance education:** Educational sessions on risk management strategies, including crop insurance, weather derivatives, and diversification, help youth farmers mitigate financial risks associated with agricultural production, such as crop failure, price fluctuations, and adverse weather conditions.

- **Access to Land**
  - **Access to land leasing and rental programs:** Facilitating access to land through leasing and rental programs that provide secure land tenure arrangements to youth farmers can enable them to start farming without the need for land ownership. Governments or landowners may offer long-term leases or affordable rental agreements tailored to the needs of youth farmers.
  - **Urban agriculture initiatives:** Supporting urban agriculture initiatives that promote small-scale farming in urban and peri-urban areas can provide opportunities for youth farmers with limited access to rural land. These initiatives may include community gardens, rooftop gardens, vacant lot cultivation, or vertical farming projects, allowing youth to engage in agricultural activities close to urban centers.
- **Access to finance and credit facilities:** Facilitating access to finance and credit facilities through tailored loan products, grants, or microfinance schemes can help youth farmers invest in agricultural inputs, equipment, and infrastructure. Financial products should be designed to accommodate the specific needs and circumstances of young agricultural entrepreneurs, with flexible repayment terms and low-interest rates.
- **Market linkages and value chains:** Strengthening market linkages and value chains for agricultural products through market information systems, networking opportunities, and support for collective marketing arrangements can enable youth farmers to access markets and sell their produce at fair prices. Training in market analysis, value addition, and quality standards can enhance their market participation and competitiveness.
- **Support wage markets:** Given the relative importance of wage labor income, consider strategies to improve wage payments and further develop wage markets to ensure that young farmers receive reasonable and improved compensation for their wage labor. This could include both agricultural and non-farm wage markets.

- **Youth empowerment and participation:** Fostering youth empowerment and participation in agricultural decision-making processes, policy dialogues, and rural development initiatives can ensure that their voices are heard, and their interests are represented. Creating platforms for youth engagement, networking, and collaboration can facilitate knowledge sharing, peer learning, and collective action among young farmers.

6.3 Recommendations for farm type 3

Farm type 3 is characterized by older female headed households who are selling close to average percentages in the market but not engaging in as much relative input purchases as well as extension services. Older women farmers often face multiple barriers to access productive resources, markets, and services. Initiatives to improve their productivity and commercialization, include:

- **Targeted Capacity Building and Training**
  - **Targeted literacy and numeracy programs:** Implementing literacy and numeracy programs specifically designed for older illiterate female farmers can empower them to better understand agricultural practices, financial transactions, and market information. These programs should be delivered in local languages and adapted to the specific needs and learning styles of older adults.
  - **Community-based extension services:** Establishing community-based extension services that prioritize outreach to older illiterate female can provide them with hands-on training, demonstrations, and practical guidance on agricultural techniques, crop management, and post-harvest practices. Extension agents should be trained to use participatory and visual teaching methods to effectively communicate with illiterate farmers.
  - **Inclusive agricultural training and demonstrations:** Organizing inclusive agricultural training sessions and demonstrations that accommodate the needs and preferences of older illiterate female farmers, such as hands-on learning, practical exercises, and visual aids, can enhance their learning experience and retention of knowledge. Training should be conducted in accessible locations and scheduled at times that are convenient for older adults.
  - **Empowerment:** Offering capacity building initiatives, leadership training, and entrepreneurship development programs specifically targeted at older female-headed households can enhance their skills, knowledge, and confidence to engage more actively in agricultural decision-making, income-generating activities, and community development initiatives. This can include training in business management, financial literacy, and women's rights and empowerment.

- **Technology adoption and mechanization:** Promoting the adoption of energy and time saving Agri-tech (e.g., Permaculture) and mechanization solutions suited to smaller landholdings can help them overcome labor shortages, increase efficiency, and reduce drudgery in farm work. This may include providing access to small-scale machinery, tools, and equipment for land preparation, planting, and harvesting.
- **Input subsidies and starter kits**: Providing input subsidies or starter kits containing essential agricultural inputs such as seeds, fertilizers, and tools to older illiterate female-headed households can lower the barriers to entry and encourage them to adopt improved farming practices. Distributing inputs through community networks or women's groups can ensure equitable access and facilitate peer learning and support.

- **Mobile agricultural information services:** Utilizing mobile phones and interactive voice response (IVR) systems to deliver agricultural information, weather forecasts, market prices, and extension messages in audio format can reach older illiterate female-headed households who may have limited access to written materials. This technology allows farmers to receive timely and relevant information directly on their mobile phones, enabling them to make informed decisions about their farming activities.
- **Gender-responsive agricultural policies:** Ensuring that agricultural policies and programs are gender-responsive and address the specific needs and priorities of older illiterate female-headed households can create an enabling environment for their participation and empowerment. This includes incorporating gender considerations into program design, implementation, and monitoring and evaluation processes to ensure that the voices and concerns of older illiterate women are heard and addressed.
- **Coordination of land market structure**: Access to land through coordinated market structures empowers elderly, female farmers to engage in agricultural production and participate in local economies. For example, improving coordination of land rental market structures to match landlords with potential tenants allows for the utilization of vacant or underutilized land through leasing arrangements, effectively preventing degradation, promoting resource efficiency, and fostering environmental sustainability.
- **Strengthening women-centered cooperatives and associations:** Support the formation and strengthening of women-centered cooperatives and associations to boost collective bargaining power and social capital.
- **Community-supported agriculture (CSA):** introduce and promote community-supported agriculture (CSA) through initiatives like community gardening. CSA participation can help elderly female farmers build resilience as they age, providing them with a support network of fellow farmers and community members who can offer assistance and companionship when needed.
- **Access to market information and value chains:** Providing older illiterate female farmers with access to market information, market linkages, and value chains can enable them to sell their produce at better prices and improve their market participation. This can involve establishing market information centers, organizing collective marketing initiatives, and facilitating access to local markets and buyers.
- **Social protection and safety nets:** Implementing social protection programs and safety nets targeted at older female-headed households can provide them with income support, healthcare benefits, and pension schemes to alleviate poverty, improve their well-being, and enhance their resilience to economic shocks and vulnerabilities.

6.4 Recommendations for farm type 4

Farm type 4 is composed of commercialized households with higher access to extension services and inputs through SNS while also having a greater livestock percentage sold compared to all other farm types. While not having as many assets as farm type 5, they appear to be operating in a relatively more entrepreneurial manner, somewhat similar to farm type 2. Here are some key policies that can be beneficial to farm type 4:

- **Capacity Building and Extension Services:**
  - **Extension services:** Strengthen extension services and farmer training programs to disseminate best practices in livestock management, animal husbandry, and farm business management.

- **Financial literacy:** Provide financial literacy training and support services to empower farmers with the knowledge and skills needed to manage their finances, access credit, and make informed investment decisions.
- **Research and innovation:** Foster collaboration between research institutions, universities, and agricultural extension agencies to promote knowledge exchange, technology transfer, and innovation in livestock production and management.

- **Livestock Production Support:**
  - **Subsidies or grants:** Provide subsidies or grants for the acquisition of high-quality breeding stock and veterinary services to improve the genetic quality and health of livestock herds. This may also involve establishing cooperative arrangements for bulk purchasing to ensure affordability and availability.
  - **Breeding programs**: Establish breeding programs to develop superior breeds that are well-adapted to local conditions and have desirable traits such as high productivity, disease resistance, and feed efficiency.
  - **Invest in infrastructure:** Investing for livestock management, including feedlots, milking parlors, and animal housing facilities, to improve efficiency and hygiene standards.
  - **Facilitate access to feed**: Facilitate access to affordable feed sources, such as subsidized fodder production or partnerships with agribusinesses for bulk purchasing of feed ingredients.
  - **Value-Added Processing:** Promote value addition in livestock products through the establishment of meat processing plants, dairy cooperatives, and leather tanneries to capture higher margins in the value chain.
- **Crop-Livestock Integration:**
  - **Adoption of integrated crop-livestock systems:** Encourage the adoption of integrated crop-livestock systems, such as rotational grazing, agroforestry, and cover cropping, to improve soil fertility, reduce erosion, and enhance productivity. Provide training and technical assistance on crop-livestock integration practices, including crop residue management, green manure production, and nutrient cycling, to optimize resource use and minimize environmental impact.
  - **Research and extension services:** Support research and extension services focused on developing crop varieties and agronomic practices that are compatible with livestock farming, such as dual-purpose crops for forage and grain production.
  - **Sustainable practices promotion:** Promoting sustainable agricultural, such as agroecology, conservation agriculture, and organic farming. Encouraging sustainable practices ensures long-term productivity, resilience, and environmental stewardship on highly commercialized farms.
- **Technology and Innovation Adoption:**
  - **Adoption of technology-driven solutions:** Encourage the adoption of technology-driven solutions for livestock management, such as electronic identification systems, remote monitoring devices, and precision feeding systems, to improve productivity, animal health, and traceability.
  - **Agricultural technology adoption and innovation:** Encouraging the adoption of advanced agricultural technologies, machinery, and practices, such as precision farming techniques, automated irrigation systems, and modern livestock management practices.

- **Research and innovation:** Support research and innovation in livestock genetics, nutrition, and disease management to develop cost-effective solutions for improving productivity and resilience in livestock production systems.
- **Adoption incentives:** Provide incentives for the adoption of renewable energy technologies, such as solar-powered water pumps and biogas digesters, to reduce energy costs and environmental footprint in livestock farming operations.

- **Strengthening farmer organizations and cooperatives:** Policy interventions strengthening farmer organizations and cooperatives benefit farmers by providing facilitating access to training in leadership and marketing and empowers them to negotiate better input deals and access larger markets.
- **Policy support and regulatory frameworks:** Developing supportive policies and regulations conducive to commercial livestock production in Rwanda, including streamlining licensing procedures, providing tax incentives, and ensuring compliance with quality and safety standards

6.5 Recommendations for farm type 5

Farm type 5 households are highly commercialized with high agricultural production and livestock value compared to all other farms.

- **Capacity Building and Extension Services:**
  - **Enhanced extension services:** Strengthen agricultural extension services to provide farmers with tailored support and training on crop and livestock management, technical assistance, and advisory support on modern farming techniques, marketing strategies, and business management.
  - **Education and skill development programs:** Invest in education and skill development programs to empower farmers with the knowledge and skills needed to adapt to changing market dynamics and technological advancements.
  - **Research and innovation:** Foster collaboration between research institutions, universities, and agricultural enterprises to promote knowledge sharing, innovation, and technology transfer in the agricultural sector.
- **Access to Resources:**
  - **Access to subsidies and credit:** Provide subsidies or low-interest loans for farmers to acquire modern farming equipment, such as tractors, harvesters, and irrigation systems.
  - **Access to quality seed:** Ensure availability and affordability of high-quality seeds, fertilizers, and pesticides through subsidies or cooperative programs.
  - **Infrastructure development and logistics:** Investing in rural infrastructure and logistics to improve connectivity and reduce post-harvest losses for highly commercialized farms. This includes upgrading roads, storage facilities, and market infrastructure, as well as establishing cold chain logistics systems to ensure the quality and freshness of agricultural products.
- **Technology Adoption:**
  - **Adoption of precision farming techniques:** Promote the adoption of precision farming techniques, such as GIS mapping, soil testing, and drones, to optimize resource utilization and improve productivity.

- **Innovative farming technologies**: Encourage the use of innovative farming technologies, such as hydroponics, aquaponics, and vertical farming, to diversify production and increase yields.

- **Market Access:**
  - **Farmer cooperatives or collective marketing groups:** Establish farmer cooperatives or collective marketing groups to negotiate better prices, access larger markets, and reduce dependence on middlemen.
  - **Market information systems:** Develop market information systems to provide farmers with real-time pricing data, market trends, and export opportunities.
  - **Value-added processing:** Facilitate the establishment of food processing units and cold storage facilities to add value to agricultural products and reduce post-harvest losses.
  - **Market development and export promotion:** Supporting market development initiatives and export promotion programs (e.g., Made in Rwanda campaign) to help wealthy farmers access lucrative domestic and international markets. This includes facilitating trade agreements, market access negotiations, and branding initiatives to showcase the quality and uniqueness of their products.
- **Sustainable Practices:**
  - **Adoption of climate-smart agricultural practices:** Promote the adoption of climate-smart agricultural practices, such as conservation tillage, agroforestry, and crop rotation, to enhance resilience to climate change and minimize environmental impact.
  - **Incentives:** Provide incentives for organic farming and certification programs to meet growing consumer demand for sustainably produced food.
  - **Research and development:** Support research and development initiatives focused on developing drought-resistant crops, pest-resistant varieties, and resilient farming systems.
- **Financial Support:**
  - **Financial incentives and subsidies:** Offer financial incentives and subsidies for adopting sustainable farming practices, such as agroecology, organic farming, and integrated pest management.
  - **Insurance schemes and risk mitigation**: Provide insurance schemes and risk mitigation measures to protect farmers against crop failures, natural disasters, and price fluctuations.
  - **Access to finance:** Establish microfinance programs and community-based savings and credit groups to improve financial inclusion and access to capital for smallholder farmers.
- **Policy support and regulatory reforms:** Reviewing existing agricultural policies and regulations to create an enabling environment for highly commercialized farms. This involves streamlining administrative procedures, reducing trade barriers, and ensuring regulatory consistency to foster investment and business growth in agriculture.

6.6 Recommendations for farm types in Group A and B

Combining the strengths of both farm Group A (wealthy, commercialized farms with high agriculture returns and large landholdings), and farm Group B (less wealthy, less commercialized farms with negative returns) can form symbiotic relationships that enhance the sustainability, productivity, and profitability of agriculture as a whole. Here are some ways they can complement each other:

- **Resource pooling and sharing programs**: incentivizing resource-sharing programs can be prioritized, encouraging wealthy farms to provide machinery, technology, and expertise to smaller farms. This can include subsidies or tax incentives for the establishment of cooperative arrangements or resource-sharing agreements.
- **Knowledge transfer initiatives:** Commercialized farms often have access to the latest agricultural research and best practices. They can provide training and knowledge transfer to smaller farms, helping them adopt more efficient and sustainable farming methods. This can involve funding for training programs, workshops, and on-farm demonstrations tailored to the needs of small-scale.
- **Contract farming and outgrower schemes:** Promote contract farming arrangements and outgrower schemes that link wealthy farmers with large farms with smallholder farmers. This provides smallholders with access to inputs, technical support, and guaranteed markets, while larger farms benefit from a diversified and reliable supply of raw materials.
- **Land access and redistribution:** Implement land tenure policies that prioritize equitable access to land for farmers with smaller land sizes through leasing arrangements, land banking programs, and land redistribution schemes. Large landholders should be incentivized to lease or subdivide underutilized land to efficient smallholder farmers, enabling them to establish viable farming enterprises.
- **Vertical integration incentives:** Offer incentives or subsidies to encourage vertical integration strategies, such as backward integration (e.g., large farms investing in processing facilities) or forward integration (e.g., small farms collaborating on branded marketing initiatives). This enhances value addition opportunities and promotes shared benefits along the value chain.
- **Input Supply Chains**: Wealthy farms can facilitate access to quality inputs such as seeds, fertilizers, and pesticides for smallholder farmers by leveraging their procurement networks and negotiating bulk discounts. This reduces input costs for small farms and improves the quality and yield of their crops.
- **Monitoring and evaluation mechanisms:** Implementing robust monitoring and evaluation is crucial for assessing the effectiveness of smallholder farmer support programs. This includes tracking key indicators, conducting surveys, and gathering feedback to ensure the initiatives reach the right beneficiaries and can be adjusted for better results.
- **Minimum wage laws and labor union support:** Strengthening minimum wage laws in agriculture ensures fair compensation for laborers, adjusting to regional economic factors. Simultaneously, supporting labor unions or agricultural worker organizations empowers workers to negotiate better wages and conditions collectively. Additionally, facilitating joint labor associations or cooperatives between wealthy and smallholder farmers fosters collaborative bargaining for equitable standards across the farming community.

REFERENCES

Anderberg, M.R. 1973 Cluster Analysis for Applications. Academic Press, New York.

Basilevsky, A. T. 2009. Statistical factor analysis and related methods: theory and applications.John Wiley & Sons.

Bidogeza, J. C., Berentsen, P. B. M., De Graaff, J., & Oude Lansink, A. G. J. M. 2009. A typologyof farm households for the Umutara Province in Rwanda. Food Security, 1(3), 321-335.

Charles, A., Azzarri, C., Haile, B., Comanescu, M., Roberts, C., & Signorelli, S. 2016. Typology Characterization of farmers in Malawi. Africa RISING Baseline Evaluation Survey (ARBES) Malawi. Intl Food Policy Res Inst.

Chen, T. S., Tsai, T. H., Chen, Y. T., Lin, C. C., Chen, R. C., Li, S. Y., & Chen, H. Y. 2005. A combined K-means and hierarchical clustering method for improving the clustering efficiency of microarray. In 2005 International symposium on intelligent signal processing and communication systems (pp. 405-408). IEEE.

Chen, B., Tai, P. C., Harrison, R., & Pan, Y. 2005. Novel hybrid hierarchical-K-means clustering method (HK-means) for microarray analysis. In 2005 (August) IEEE Computational Systems Bioinformatics Conference-Workshops (CSBW'05) (pp. 105-108). IEEE. DOI: 10.1109/CSBW.2005.98

Chen, B., He, J., Pellicer, S., & Pan, Y. 2010. Using Hybrid Hierarchical K-means (HHK) clustering algorithm for protein sequence motif Super-Rule-Tree (SRT) structure construction. International journal of data mining and bioinformatics, 4(3), 316-330. https://doi.org/10.1504/IJDMB.2010.033523

Cunningham, W. V., & Maloney, W. F. 2001. Heterogeneity among Mexico's microenterprises: An application of factor and cluster analysis. Economic Development and Cultural Change, 50(1), 131-156.

Everitt, B.S., Landau, S. and Leese, M. 2001.Cluster Analysis. 4th Edition, Arnold, London.

Everitt, B. S. 1993. Cluster Analysis. 3rd ed. London: Arnold.

Harman, H.H. 1976. Modern Factor Analysis. 3rd Edition, The University of Chicago Press, Chicago.

Kaufman, L., & Rousseeuw, P. J. 2009. Finding groups in data: an introduction to cluster analysis. John Wiley & Sons.

Kassambara, A. 2017. Practical guide to cluster analysis in R: Unsupervised machine learning. 1 vol. (187 p.). Sthda.

Kim, J. O., & Mueller, C. W. 1978. Factor Analysis: Statistical Methods and Practical Issues. Beverly Hills, CA: Sage.

McDonald, R. P. 2014. Factor analysis and related methods. Psychology Press. 1st Edition (First Published 1985) New York. https://doi.org/10.4324/9781315802510

Młodak, A. 2021. k-means, Ward and probabilistic distance-based clustering methods with contiguity constraint. Journal of Classification, 38(2), 313-352.

Neza, B.N., Higiro, J., Mwangi, L.W. and Ochatum, N. 2021. Institutionalizing farmer field schools – Twigire Muhinzi National Extension System in Rwanda. *Rome, FAO and IFPRI*. https://doi.org/10.4060/cb7131en

Nielsen, F. 2016. Introduction to HPC with MPI for Data Science. Springer.p163-207.

Peterson, A. D., Ghosh, A. P., & Maitra, R. 2018. Merging K-means with hierarchical clustering for identifying general-shaped groups. Stat, 7(1), e172.

Reynolds, A. P., Richards, G., de la Iglesia, B., & Rayward-Smith, V. J. 2006. Clustering rules: a comparison of partitioning and hierarchical clustering algorithms. Journal of Mathematical Modelling and Algorithms, 5, 475-504.

Sinharay, S. 2010. An Overview of Statistics in Education. In: Peterson, P., et al., Eds., International Encyclopedia of Education, 3rd Edition, Elsevier Ltd., Amsterdam, 1-11.

Signorelli, Sara, Carlo Azzarri, and Beliyou Haile. 2016. Typology characterization of farmers in Africa RISING sites in Malawi.

Steinley, D. 2006. K-means clustering: a half-century synthesis. British Journal of Mathematical and Statistical Psychology, 59(1), 1-34.

Timler, C. J., Michalscheck, M., Klapwijk, C. J., Mashingaidze, N., Ollenburger, M. H., Falconnier, G. N., & Groot, J. C. 2014. Characterization of farming systems in Africa RISING intervention sites in Malawi, Tanzania, Ghana and Mali.

ANNEXES

Annex 1: Empirical Methodology

A. Factor Analysis

Factor analysis finds a small number of common factors that linearly reconstruct a large number of variables (Cunningham and Maloney 2001, Harman 1976, and Kim and Mueller 1978).

$$Z_{ij} = \sum_{p=1}^{k} F_{ip} a_{pj} + e_{ij} \ , \qquad (1)$$

where Z_{ij} is the value of the ith observation on the *j*th variable, F_{ip} is the ith observation on the *p*th common factor, a_{pj} is a set of linear coefficients or factor loadings, and e_{ij} is known as the jth variable's unique factor and is analogous to the residual in standard regression analysis. The factors themselves are linear combinations of the variables such that:

$$F_{pi} = \sum_{j=1}^{k} q_{pj} z_{ji} \qquad (2)$$

where F_{pi} is the value of factor p for individual i with observations on k variables, and q is the weighting in the pth factor of variable j. By isolating pj a subset of the h possible factors, a large and seemingly random mass of data can be found to be structured along a few critical dimensions.[9]

The technique has four attractive features that aid in teasing out the composition and dynamics of agricultural farm systems. First, it isolates covarying variables that suggest types of farms, which would not be possible from simple bivariate cross correlations, again, without imposing any prior structure on the data. Second, if in fact there are "better-off" and "worse-off" farmers, we should be able to identify a dualistic factor that loads heavily on the characteristics commonly associated with farm quality.

Third, since the value of any particular factor differs for each observation, the factor will show a distribution that offers a statistical test for dualism. If, in fact, there are two types of firms with distinctive modes of operation and dynamics, we might expect the observed distribution to comprise two underlying distributions corresponding to the inferior and superior subsectors:

$$F \sim pN(\mu_2, \sigma_1^2) + (1-p)N(\mu_2, \sigma_1^2) \qquad (3)$$

Using the expectation–maximization (EM) algorithm, we maximize the likelihood across both means, both standard deviations, and the weighting on each distribution (the share of the population found in each segment) p and $(1-p)$.

In order to test against the null hypothesis that the data are drawn from a single normal distribution, we then compare the likelihoods. And fourth, because the factors are mutually orthogonal by construction, no factor can be influencing either the weights or the distributions of the others.[10]

[9] Calculated eigenvalues reveal how much of the variation occurs along each dimension. We chose a subset with the highest explanatory power and rotated the resulting matrix again to aid in interpretation by re-expressing the factors so that the loadings of a few variables are as large as possible. Rather than using the common maximum likelihood or other methods, we employed the principal component method of extracting factors because it does not require normality in the distribution of the variables. Although the various alternative rotation methods yielded similar results, the Varimax method offered the clearest separation of factors and preserved the orthogonality of the initial factors.

[10] Since the identified factors may be sensitive to the variables included in the analysis, we ran several specifications. More specifically, variables with very high loadings were eliminated to see if those variables alone were driving the factor. In general, the same factors were formed with the same economic interpretations.

B. Cluster Analysis-Ward clustering

The Ward clustering method assigns observations with similar agricultural farm characteristics into progressively larger endogenously determined clusters by minimizing the sum of the within-group variance of all clusters[11] (Cunningham and Maloney 2001; Dubes 1988 and Anderberg, 1973).

Assuming that there are $i = p\ 1, \ldots, n$ observations with $j = p\ 1, \ldots, k$ variables for each i, and that the number of clusters ranges from 1 (where all i are assigned to the same cluster) to n (where each i has its own cluster), we minimize the error sum of squares:

$$W = \sum_{m=1}^{m=j} \sum_{j=1}^{j=k} \sum_{i=1}^{i=n_m} (x_{ijm} - \overline{x_{jm}})^2 \qquad (4)$$

where x_{ijm} is the value of the jth variable for the ith of n_m observations in the mth cluster and $\overline{x_{jm}}$ is the mean value of variable j in the

mth cluster. The iterative process begins with $g = n$ clusters that each consist of a single observation ($n_m = 1$) and calculates that the distance of the n observations from the n cluster centers (themselves) is 0.

In the next step, two clusters are combined such that the error sum of squares is minimized and there is $m = n - 1$ clusters, where $n - 2$ clusters have a single observation, and one cluster has two observations. The process continues as more distant points are forced to share a common center until $n_m = n$ and $m = 1$. The optimal number of clusters g^* is selected from the n Ward values (W) that were generated in the process, and each observation is assigned to the nearest centroid, that is, mean vector.[12]

[11] Cluster analysis requires some prior manipulation of the data. First, it is very sensitive to magnitudes, so each variable is normalized to a scale with a range of [0, 1]. Second, extreme values or outliers compress the bulk of the observations into a very limited range and yield trivial clustering results. In some cases, therefore, these values are suppressed or recoded to provide a greater variance across most of the sample.

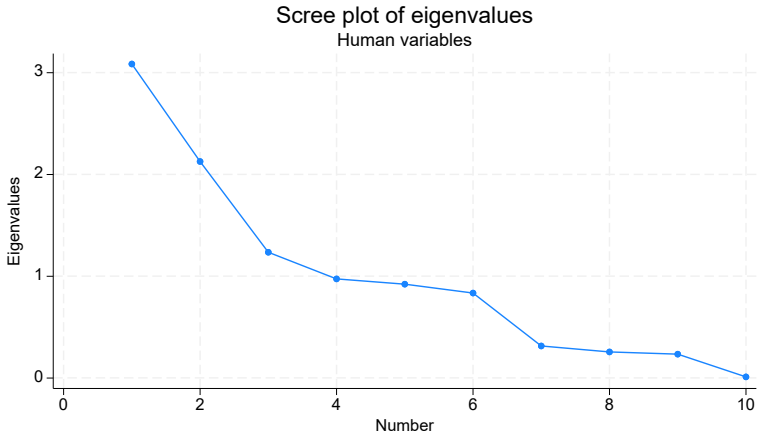
[12] The *n* values are used in two ways to determine the number of clusters. First, a dendrogram graphically depicts the hierarchical combination process as clusters are formed and consolidated, which suggests the appropriate level of consolidation. A second, and related, method is to stop clustering when the Ward value rises above a certain threshold, or the second derivative of the plot suddenly increases. This is revealed when agglomerations are relatively more forced and where the data should be left in distinct subclusters. We assigned observations to clusters using the standard k-medians Method (MacQueen, 1967; Steinhaus, 1956) with the objective to efficiently determine a set of k centers that minimize either the squared `2 or the `1 distance, respectively, of the input vectors to their closest center. T-tests were performed to measure statistical significance at the cluster level.

Annex 2: Factor Analysis Results

1. Factor analysis of human variables

Figure 10 illustrate the factorization from scree plot of the human variables where the first three factors (represented by the first three dots at the top-of-the-line graph) are highly relevant but that the 4th factor starts to be less important in explaining the variation (smaller vertical jump). Therefore, only three factors have been selected.

Figure A12: Scree plot - Human variables



Source: Authors' calculations
Note: X-axis indicates the number of factor scores.

Table 7 depicts the matrix of factor loads for the selected two factors, highlighted variables with the highest absolute values of factor loads (>0.5 or <-0.5) defines well the factor. Factor 1 captures elements related to household head characteristics, marital status, sex, education, and literacy status while factor 2 is related to household size, adult equivalent, and maturity of household head. Considering the correlation among the selected variables, cluster analysis only includes adult equivalent, sex, age and literacy status of the household head.

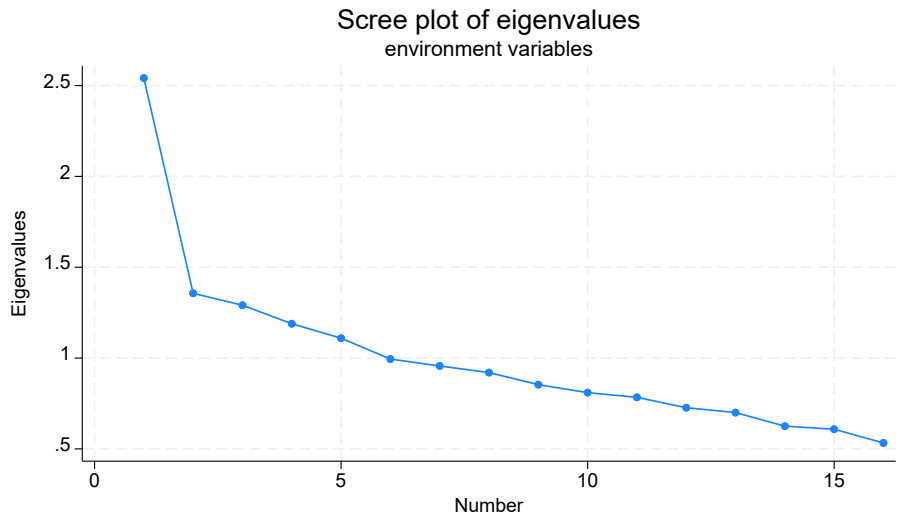
Table A7. Factor analysis of social-human variables

No	Variable	Factor1	Factor2
1	Household Diversity Score	0.07	-0.15
2	Household size	0.59	0.74
3	Adult equivalent	0.57	0.75
4	Household head is widow/widower	-0.74	0.03
5	Household head is single	-0.02	-0.38
6	Household head is female	-0.70	-0.10
7	Household head's age	-0.65	0.46
8	Household head is young	0.34	-0.69
9	Household head years of education	0.63	-0.32
10	Household head is literate	0.66	-0.25

Source: Authors' calculations.
Note: Factor; unobserved variables that summarize the correlation among observed human variables.

2. Factor analysis of environment and social variables

Figure A13: Scree plot - Environment and social variables



Source: Authors' calculations.
Note: X-axis indicates the number of factor scores.

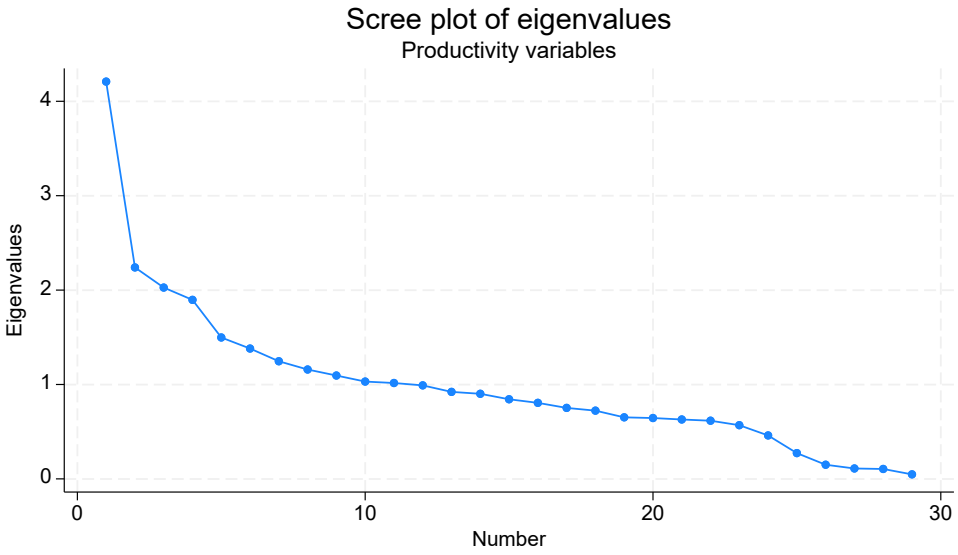
Table A8. Factor analysis of environmental variables

No	Variable	Factor1	Factor2
1	Inorganic fertilizers use	0.65	-0.04
2	Organic fertilizer use	0.45	-0.29
3	Pesticide/Fungicide use	0.55	-0.15
4	Erosion control	0.31	-0.45
5	Irrigation application	0.42	0.02
6	Monocropping application	0.23	-0.25
7	Access to extension services	0.52	-0.01
8	Household belong to Twigire Muhinzi/Mworozi	0.35	0.60
9	Household belong to farmer field school	0.38	0.61
10	Mean distance in minutes from homestead to plot	0.08	0.13
11	Mean distance in minutes from plot to market	0.05	-0.01
12	Household owing mobile phone	0.37	-0.01
13	Current member of cooperative	0.50	0.25
14	Access to fertilizer and seed through SNS extension	0.52	-0.05
15	Household migrated	-0.11	0.26

Source: Authors' calculations
Note: Factor; unobserved variables that summarize the correlation among observed human variables.

3. Factor analysis of productivity variables

Figure A14: Scree plot - Productivity variables



Source: Authors' calculations.
Note: X-axis indicates the number of factor scores

Table A9. Factor analysis of productivity variables

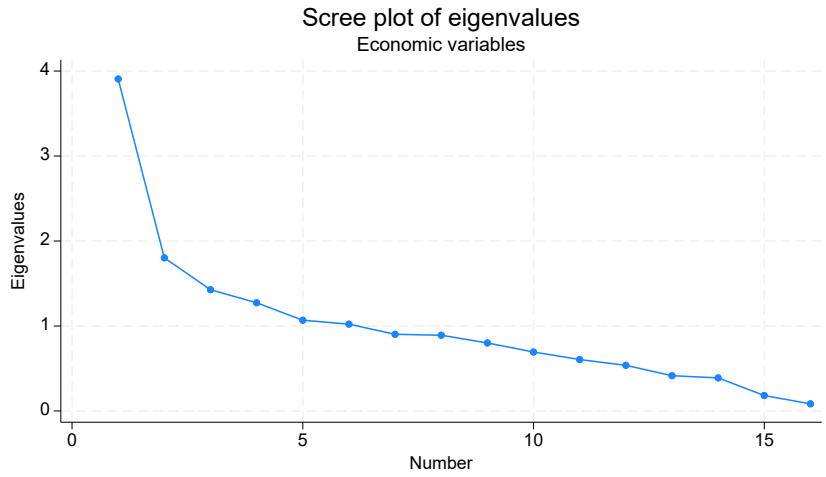
No	Variable	Factor1	Factor2
1	Total landholding	0.62	-0.17
2	Agricultural landholding	0.59	-0.13
3	Agricultural landholding under LUC	0.25	-0.07
4	Household own land	0.31	0.06
5	Fallow application	0.23	-0.07
6	Household produce cereal	0.12	-0.07
7	Household produce veg/legumes	0.23	0.03
8	Household produce roots/tubers	0.28	0.07
9	Household produce banana	0.36	0.12
10	Household produce fruits	0.30	0.13
11	Household produced cash crop	0.37	0.75
12	Number of all crops produced	0.69	0.19
13	Number of marketed crops	0.73	0.16
14	Number of marketed food crop	0.55	-0.05
15	Number of marketed cash crop	0.36	0.76
15	Maize yield	0.05	-0.07
17	Bean yield	-0.01	-0.06
18	Cassava yield	0.06	0.15
19	Irish potatoes yield	0.05	-0.12
20	Sweet potatoes yield	0.04	-0.03

No	Variable	Factor1	Factor2
21	Climbing beans yield	0.13	0.01
22	Coffee yield	0.16	0.63
23	Household own livestock	0.47	-0.19
24	Tropical livestock unit	0.62	-0.40
25	Number of owned chickens	0.18	-0.20
26	Number of eggs produced	0.27	-0.14
27	Liter of milk produced	0.39	-0.27
28	Household own small ruminant	0.34	-0.22
29	Household own big ruminant	0.54	-0.34

Source: Authors' calculations.
Note: Factor; unobserved variables that summarize the correlation among observed human variables.

4. Factor analysis of economic variables

Figure A15: Scree plot - Economic variables



Source: Authors' calculations.
Note: X-axis indicates the number of factor scores.

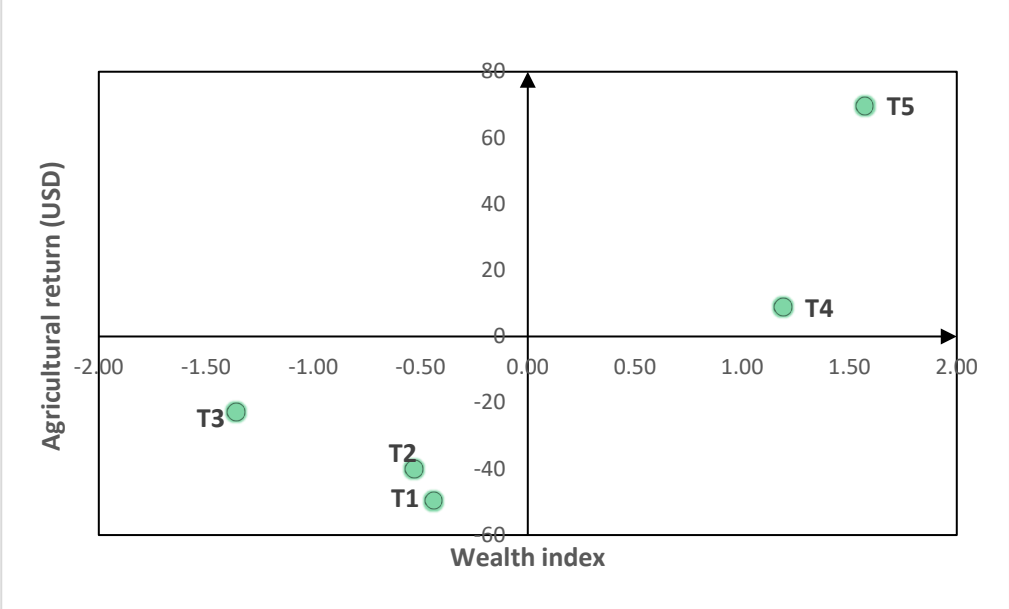
Table A10. Factor analysis of economic variables

No	Variables	Factor1	Factor2	Factor3
1	Total Agriculture production value	0.87	0.04	-0.01
2	Household return (Agri&livestock)	0.45	0.78	-0.06
3	Production kept for home consumption value	0.64	0.01	0.04
4	Percentage value sold	0.59	-0.17	-0.10
5	Total fertilizer and pesticide cost	0.56	-0.39	0.09
6	Household seed cost	0.23	-0.37	0.23
7	Household transport cost	0.30	-0.17	0.14
8	Crop implicit Gross Margin	0.74	0.42	-0.08
9	Livestock implicit Gross Margin	0.43	0.47	0.14
10	Household hired in labor	0.50	-0.41	0.10
11	Household sold livestock	0.40	0.26	0.22
12	Wealth index	0.56	-0.28	0.31
13	Household have accessed to wage income	-0.40	0.23	0.63
14	Household have accessed to business income	0.19	-0.19	0.34
15	Household have accessed to vup	-0.16	0.15	0.01
16	Household have accessed to off farm income	-0.25	0.16	0.80

Source: Authors' calculations.
Note: Factor; unobserved variables that summarize the correlation among observed human variables.

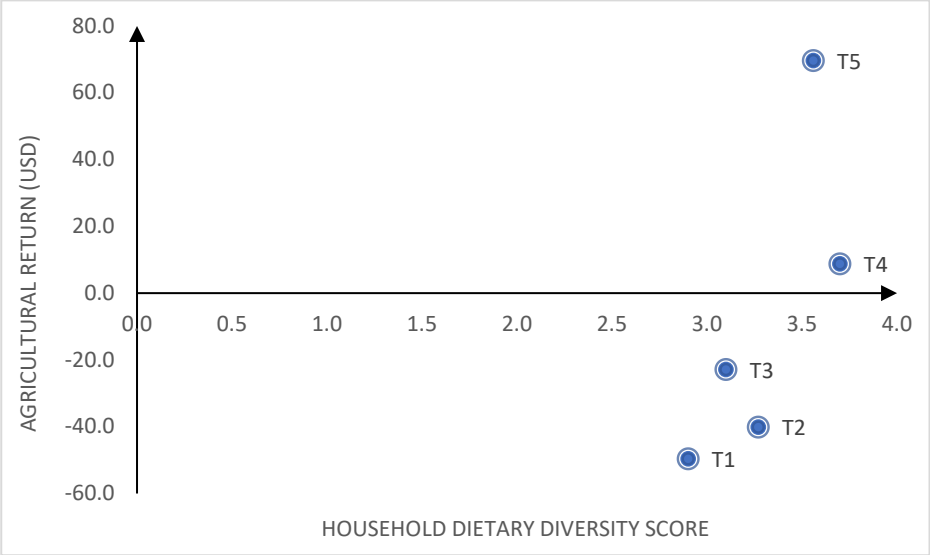
Annex 3: Different Distribution of Farm Types

Figure A16: Distribution of Typologies by wealth index and agricultural return



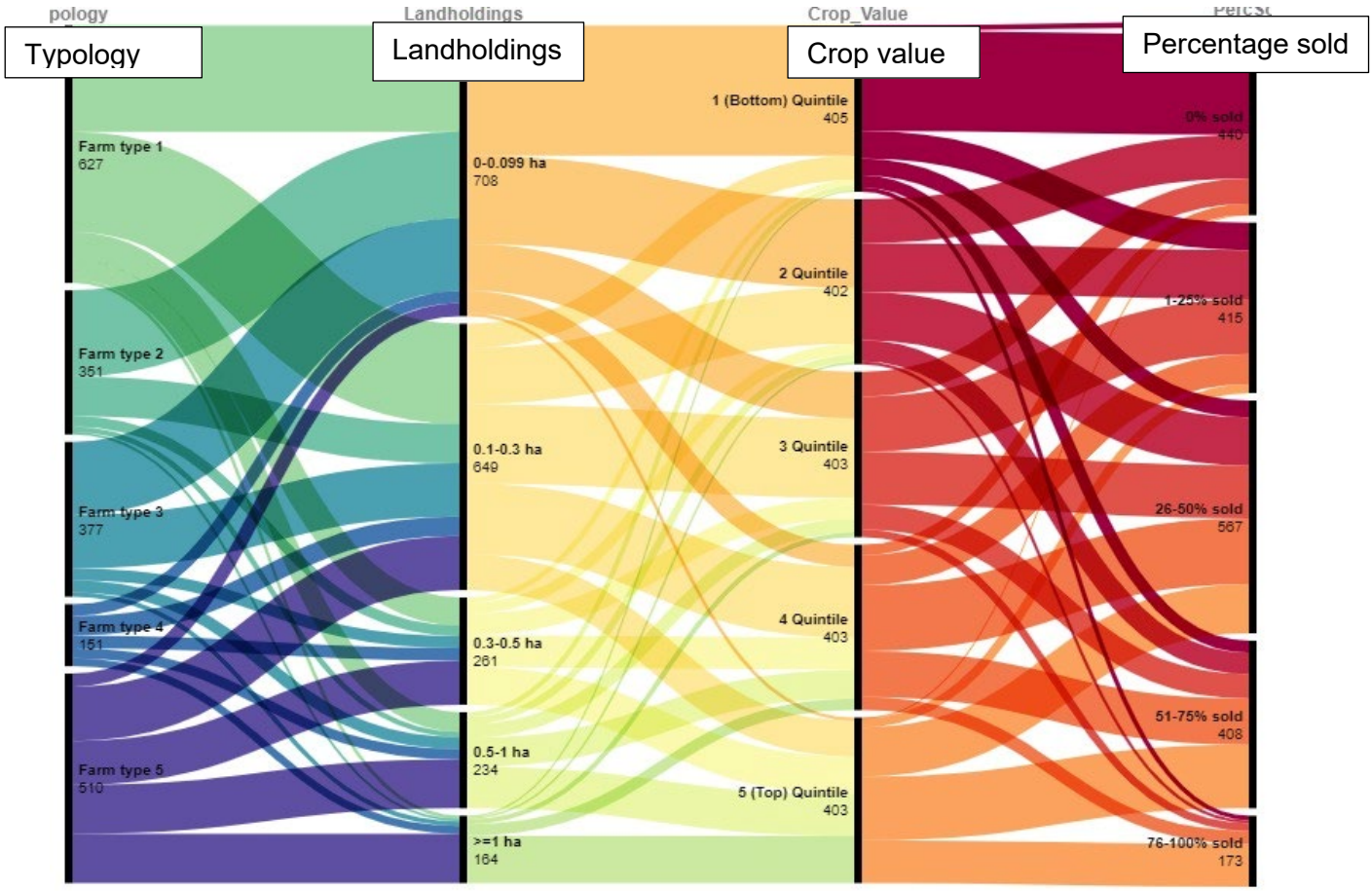
Source: Authors' calculations.
Note: Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

Figure A17: Distribution household Dietary Diversity across farm type



Source: Authors' calculations.
Note: Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households.

Figure A18: Farm Typologies, landholdings, crop value and commercialization distribution



Source: Authors' calculations.
Note: Farm type 1: less commercialized male headed households, Farm type 2: educated youth headed household, Farm type 3: older female headed households, Farm type 4: moderate wealthier households, Farm type 5: wealthier households; Quintile 1: Very high crop value, Quintile 2: High crop value, Quintile 3: Medium crop value, Quintile 4: Low crop value, Quintile 5: Very low crop value.

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
1201 Eye St, NW | Washington, DC 20005 USA
T. +1-202-862-5600 | F. +1-202-862-5606
ifpri@cgiar.org
www.ifpri.org | www.ifpri.info

IFPRI-RWANDA
KG 563 Street #7, Kacyiru
P.O. Box 1269 | Kigali, Rwanda
IFPRI-Rwanda@cgiar.org
www.rwanda.ifpri.info

The Rwanda Strategy Support Program (Rwanda SSP) is managed by the International Food Policy Research Institute (IFPRI). Funding support for Rwanda SSP is provided by the European Union (EU); the United States Agency for International Development (USAID); and the CGIAR Research Program on Policies, Institutions, and Markets. This publication has been prepared as an output of Rwanda SSP. It has not been independently peer reviewed. Any opinions expressed here belong to the author(s) and do not necessarily reflect those of IFPRI, EU, USAID, or CGIAR.